Ministry of
Northern Development
and Mines
Ontario

Aggregate Resources Inventory of Laxton, Digby and Longford and Dalton Townships

Victoria County

Ontario Geological Survey
Aggregate Resources Inventory
Paper 153

By Staff of the Sedimentary and Environmental Geoscience Section,
Ontario Geological Survey

1992

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ISSN 0708–2061
ISBN 0-7778-0053-5

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Canadian Cataloguing in Publication Data

Main entry under title:

Aggregate resources inventory of Laxton, Digby and Longford and Dalton townships, Victoria County

(Ontario Geological Survey aggregate resources inventory paper, ISSN 0708–2061; 153)
ISBN 0–7778-0053-5

1. Aggregates (Building materials)––Ontario––Victoria (County). I. Ontario Geological Survey. Sedimentary and Environmental Geoscience Section. II. Ontario. Ministry of Northern Development and Mines. III. Series.

TN939.A33 1992 553.6'2'0971364 C92–092577–4

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Cette publication est disponible en anglais seulement.

Parts of this publication may be quoted if credit is given. It is recommended that reference be made in the following form:

Ontario Geological Survey 1992. Aggregate resources inventory of Laxton, Digby and Longford and Dalton townships, Victoria County; Ontario Geological Survey, Aggregate Resources Inventory Paper 153, 45p.

500–92–Maracle Press

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Abstract

This report includes an inventory and an evaluation of sand and gravel resources, as well as a discussion of bedrock aggregate potential, for Laxton, Digby and Longford and Dalton townships, in Victoria County. This report is based on a detailed field assessment undertaken in the summer of 1990 and on previous studies of the area. The investigation was conducted to delineate and determine the quality and quantity of aggregate within the area to help ensure that sufficient aggregate resources are available for future use.

In general, the townships contain only limited resources of sand and gravel. Several deposits have, however, been grouped together into 3 Selected Sand and Gravel Resource Areas of primary significance. These Resource Areas consist of subaqueous fans and ice-contact stratified drift deposits which occupy an available area of approximately 415 ha and contain an estimated 35.4 million tonnes of sand and gravel. Although there are only minor amounts of crushable gravel, a variety of sand products including road subbase and Select Subgrade Material are available from these deposits. In addition to the Selected Resource Areas, numerous deposits have been classified as resources of secondary significance which add considerably to the resource base of the area.

Potential resources of high quality aggregate do exist in the townships within 2 Selected Bedrock Resource Areas in the southern parts of the report area. The Resource Areas consist of bedrock of the Gull River and Bobcaygeon formations which are overlain by less than 8 m of drift. The limestones of these formations are well suited for aggregate production. An estimated 7600 ha are currently available for extraction in these selected deposits, containing possible resources of 3600 million tonnes. In addition, hard and durable Precambrian bedrock is an alternate potential source of crushed stone in the area.

Selected Resource Areas are not intended to be permanent, single land use units. They represent areas in which a major resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection.

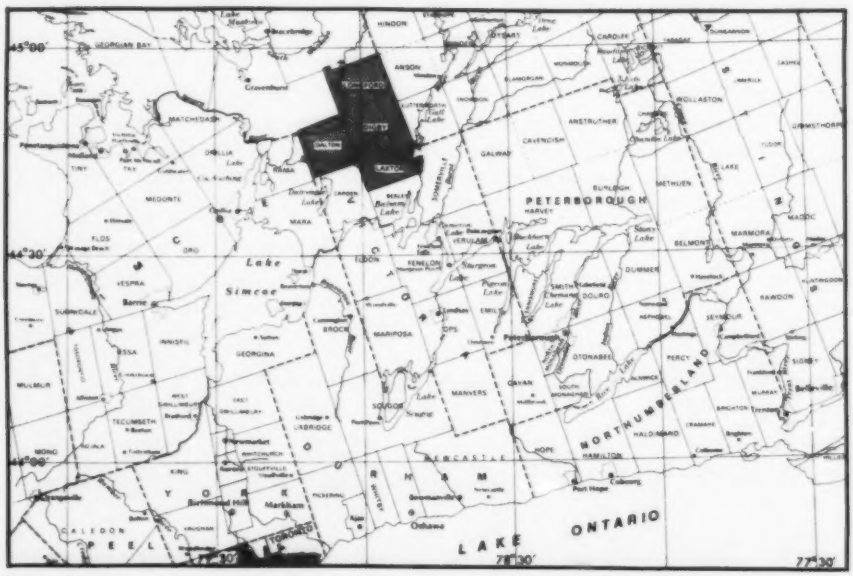


Figure 1. Key map showing the location of Laxton, Digby and Longford and Dalton townships, Victoria County, scale 1:1 800 000.

Résumé

Ce rapport comprend un inventaire et une évaluation des ressources en sable et en gravier, ainsi qu'un exposé sur le potentiel en agrégat du substratum des cantons de Laxton, Digby et Longford et Dalton dans le comté de Victoria. Ce rapport est basé sur une évaluation détaillée faite sur le terrain au cours de l'été 1990 et sur des études préalables du secteur. Cette étude a été entreprise dans le but de délimiter la présence d'agrégat dans le secteur et d'en déterminer la qualité et la quantité afin de s'assurer que les ressources en agrégat disponibles sont suffisantes pour des utilisations futures.

En général, les cantons ne recèlent que des ressources limitées de sable et de gravier. On a pu néanmoins regrouper quelques dépôts en trois zones choisies de sable et de gravier d'une importance primordiale. Ces zones ressources comprennent des cône de dejection subaquatique et des dépôts du drift de contact glaciare stratifé, qui occupent une superficie disponible de 415 hectares et recèlent environ 35.4 millions de tonnes de sable et de gravier. Bien qu'on n'y trouve que de faibles quantités de gravier concassable, on peut tirer une gamme de produits du sable de ces dépôts, y compris le matériel de soubassement routier et de sous-grade sélectif. En dehors des zones ressources choisies, on a classé plusieurs dépôts de ressources d'une importance secondaire, ce qui augmente considérablement les ressources potentielles de la région.

Les ressources potentielles en agrégats de haute qualité existent effectivement dans la partie sud des cantons, à l'intérieur de deux zones ressources choisies se rattachant au socle. Les zones ressources contiennent le socle des formations de Gull River et de Bobcaygeon, recouvertes d'une couche de drift inférieure à 8 m. Les calcaires de ces formations conviennent à la production d'agrégats. On dispose actuellement d'une superficie d'environ 7 600 hectares de ces gisements choisis, ce qui permettrait d'exploiter des ressources possibles de 3 600 millions de tonnes. En outre, le socle précambrien contient une roche dure et résistante qu'on pourrait exploiter comme source alternative de la pierre concassée dans la région.

Les zones sélectionnées pour leurs ressources ne sont pas destinées à un usage unique et permanent. Elles représentent des zones dans lesquelles une ressource importante a été reconnue et peuvent être réservées entièrement ou partiellement pour l'exploitation et/ou comme réserves de ressources.

Cette publication est disponible en anglais seulement.

Aggregate Resources Inventory of Laxton, Digby and Longford and Dalton Townships

Victoria County

By Staff[1] of the Sedimentary and Environmental Geoscience Section

1. Project Supervisor: I. Szoke; field work and report by G.R. Jones; compilation and drafting by Staff of the Aggregate Assessment Office. Assistance with review provided by the Regional Geologists, Ministry of Northern Development and Mines, Dorset and Tweed, Ontario and the Mineral Resources Staff, Minden and Lindsay Area Offices, Ministry of Natural Resources.

Manuscript accepted for publication by Chief, Sedimentary and Environmental Geoscience Section, September 17, 1992. This report is published with the permission of V.G. Milne, Director, Ontario Geological Survey.

Introduction

Mineral aggregates, which include bedrock-derived crushed stone as well as naturally formed sand and gravel, constitute the major raw material in Ontario's road-building and construction industries. Very large amounts of these materials are used each year throughout the Province. For example, in 1987, the total tonnage of mineral aggregates extracted was 142 million tonnes, greater than that of any other metallic or nonmetallic commodity mined in the Province (Ontario Ministry of Northern Development and Mines 1989).

Although mineral aggregate deposits are plentiful in Ontario, they are fixed-location, nonrenewable resources which can be exploited only in those areas where they occur. Mineral aggregates are characterized by their high bulk and low unit value so that the economic value of a deposit is a function of its proximity to a market area as well as its quality and size. The potential for extractive development is usually greatest in areas where land use competition is extreme. For these reasons the availability of adequate resources for future development is now being threatened in some areas.

Comprehensive planning and resource management strategies are required to make the best use of available resources, especially in those areas experiencing rapid development. Such strategies must be based on a sound knowledge of the total mineral aggregate resource base at both local and regional levels. The purpose of the Aggregate Resources Inventory is to provide the basic geological information required to include potential mineral aggregate resource areas in planning strategies. The reports should form the basis for discussion on those areas best suited for possible extraction. The aim is to assist decision-makers in protecting the public well-being by ensuring that adequate resources of mineral aggregate remain available for future use.

This report is a technical background document, based for the most part on geological information and interpretation. It has been designed as a component of the total planning process and should be used in conjunction with other planning considerations, to ensure the best use of the resources.

The report includes an assessment of sand and gravel resources as well as a discussion on the potential for bedrock-derived aggregate. The most recent information available has been used to prepare the report. As new information becomes available, revisions may be necessary.

Part I — Inventory Methods

FIELD AND OFFICE METHODS

The methods used to prepare the report primarily involve the interpretation of published geological data such as bedrock and surficial geology maps and reports (*see References*) as well as field examination of potential resource areas. Field methods include the examination of natural and man-made exposures of granular material. Most observations are made at quarries and sand and gravel pits located from records held by the Ontario Ministry of Transportation, the Ontario Geological Survey, and Regional and District offices of the Ontario Ministry of Natural Resources. Observations made at pit sites include estimates of the total face height and the proportion of gravel- and sand-sized fragments in the deposit. Observations are also made of the shape and lithology of the particles. These characteristics are important in estimating the quality and quantity of the aggregate. In areas of limited exposure, subsurface materials may be assessed by hand augering and test pitting.

Deposits with potential for further extractive development or those where existing data are scarce, are studied in greater detail. Representative sections in these deposits are sampled in 11 to 45 kg units from existing pit faces or from test pits. The samples are analyzed for grain size distribution, and in some cases the Los Angeles abrasion and impact test, absorption, and Magnesium Sulphate soundness tests and petrographic analyses are carried out. Analyses are performed either in the laboratories of the Ontario Ministry of Transportation, or in the Geoscience Laboratory, Ontario Geological Survey.

The field data are supplemented by pit information on file with the Soils and Aggregates Section of the Ontario Ministry of Transportation. Data contained in these files include field estimates of the depth, composition and "workability" of deposits as well as laboratory analyses of the physical properties and chemical suitability of the aggregate. Information concerning the development history of the pits and acceptable uses of the aggregate is also recorded. The locations of additional sources were obtained from records held by Regional and District offices of the Ontario Ministry of Natural Resources. The co-operation of the above-named groups in the compilation of inventory data is gratefully acknowledged.

Aerial photographs at various scales are used to determine the continuity of deposits, especially in areas where information is limited. Water well records, held by the Ontario Ministry of the Environment, are used in some areas to corroborate deposit thickness estimates or to indicate the presence of buried granular material. These records are used in conjunction with other evidence.

Topographic maps of the National Topographic System, at a scale of 1:50000, are used as a compilation base for the field and office data. The information is then transferred to a base map, also at a scale of 1:50000. These base maps are prepared by the Land and Resource Information Branch, Ontario Ministry of Natural Resources with information taken from maps of the National Topographic System by permission of Energy, Mines and Resources Canada, for presentation in the report.

RESOURCE TONNAGE CALCULATION TECHNIQUES

SAND AND GRAVEL RESOURCES

Once the interpretative boundaries of the aggregate units have been established, quantitative estimates of the possible resources available can be made. Generally, the volume of a deposit can be calculated if its areal extent and average thickness are known or can be estimated. The computation methods used are as follows. First, the area of the deposit, as outlined on the final base map, is calculated in hectares. The thickness values used are an approximation of the deposit thickness, based on the face heights of pits developed in the deposit or on subsurface data such as test holes and water well logs. Tonnage values can then be calculated by multiplying the volume of the deposit by 17 700 (the density factor). This factor is approximately the number of tonnes in a 1 m thick layer of sand and gravel, 1 ha in extent, assuming an average density of 1770 kg/m^3.

Tonnage = Area x Thickness x Density Factor

Tonnage calculated in this manner must be considered only as an estimate. Furthermore, such tonnages represent amounts that existed prior to any extraction of material (i.e., original tonnage) (Table 1, Column 4).

The Selected Sand and Gravel Resource Areas in Table 3 are calculated in the following way. Two successive subtractions are made from the total area. Column 3 accounts for the number of hectares unavailable because of the presence of permanent cultural features and their associated setback requirements. Column 4 accounts for those areas that have previously been extracted (e.g., wayside and abandoned pits are included in this category). The remaining figure is the area of the deposit currently available for extraction (Column 5). The available area is then multiplied by the estimated deposit thickness and the density factor (Column 5 x Column 6 x 17 700) to give an estimate of the sand and gravel tonnage (Column 7) presently available for extractive development and/or resource protection.

Resource estimates are calculated for deposits of primary significance. Resource estimates for deposits

of secondary and tertiary significance are not calculated in Table 3, however, the aggregate potential of these deposits is discussed in the report.

BEDROCK RESOURCES

The method used to calculate resources of bedrock-derived aggregate is much the same as that described above. The areal extent of bedrock formations overlain by less than 15 m of unconsolidated overburden is determined from bedrock geology maps, drift thickness and bedrock topography maps, and from the interpretation of water well records. The measured extent of such areas is then multiplied by the estimated quarriable thickness of the formation, based on stratigraphic analyses and on estimates of existing quarry faces in the unit. In some cases a standardized estimate of 18 m is used for thickness. Volume estimates are then multiplied by the density factor [the estimated weight in tonnes of a 1 m thick section of rock, 1 ha in extent].

Resources of dolostone are calculated using a density factor of 2649 kg/m^3, sandstone resources are calculated using a density estimate of 2344 kg/m^3 and shale resources are calculated with a factor of 2408 kg/m^3.

UNITS AND DEFINITIONS

The measurements and other primary data available for resource tonnage calculations are given in Metric units in the text and on the tables which accompany the report. Data are generally rounded off in accordance with the Ontario Metric Practice Guide (Metric Committee 1975).

The tonnage estimates made for sand and gravel deposits are termed possible resources (*see* Glossary, Appendix B) in accordance with terminology of the Ontario Resource Classification Scheme (Robertson 1975, p.7) and with the Association of Professional Engineers of Ontario (1976).

Part II — Data Presentation and Interpretation

Two maps, each portraying a different aspect of the aggregate resources in the area, accompany the report. Map 1, "Sand and Gravel Resources", gives a comprehensive inventory and evaluation of the sand and gravel resources in the report area. Map 2 "Bedrock Resources", shows the distribution of Paleozoic bedrock formations, the areas of undifferentiated Precambrian bedrock, the thickness of overlying unconsolidated sediments and identifies the Selected Bedrock Resource Areas.

MAP 1: SAND AND GRAVEL RESOURCES

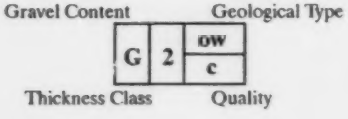
Map 1 shows the extent and quality of sand and gravel deposits within the study area and an evaluation of the aggregate resources. The map is derived from existing surficial geology maps of the area or from aerial photograph interpretation in areas where surficial mapping is incomplete.

The present level of extractive activity is also indicated on Map 1. Sand and gravel pits are identified by a numbered dot on the map and described in Table 2. Each description notes the estimated face height of the pit and the estimated percentage of gravel it contains.

Map 1 also presents a summary of available information related to the quality of aggregate contained in all the known aggregate deposits in the study area. Much of this information is contained in the symbols which are found on the maps. The Deposit Symbol appears for each mapped deposit and summarizes important genetic and textural data. The Texture Symbol is a circular proportional diagram which displays the grain size distribution of the aggregate in areas where bulk samples were taken.

DEPOSIT SYMBOL

The Deposit Symbol is similar to those used in soil mapping and land classification systems commonly in use in North America. The components of the symbol indicate the gravel content, thickness of material, origin (type) and quality limitations for every deposit shown on Map 1. These components are illustrated by the following example:



This symbol identifies an outwash deposit 3 to 6 m thick containing more than 35% gravel. Excess silt and clay may limit uses of the aggregate in the deposit.

The "gravel content" and "thickness class" are basic criteria for distinguishing different deposits. The "gravel content" symbol is an upper case "S" or "G". The "S" indicates that the deposit is generally "sandy" and that gravel-sized aggregate (greater than 4.75 mm) makes up less than 35% of the whole deposit. "G" indicates that the deposit contains more than 35% gravel.

The "thickness class" indicates a depth range which is related to the potential resource tonnage for each deposit. Four thickness class divisions have been established as shown in the legend for Map 1.

Two smaller sets of letters, divided from each other by a horizontal line, follow the thickness class number. The upper series of letters identifies the geologic deposit type (the types are summarized with respect to their main geologic and extractive characteristics in Appendix C) and the lower series of letters identifies the main quality limitations that may be present in the deposit as discussed in the next section.

TEXTURE SYMBOL

The Texture Symbol provides a more detailed assessment of the grain size distribution of material sampled during field study. These symbols are derived from the information plotted on the aggregate grading curves found in the report. The relative amounts of gravel, sand, and silt and clay in the sampled material are shown graphically in the Texture Symbol by the subdivision of a circle into proportional segments. The following example shows a hypothetical sample consisting of 30% gravel, 60% sand, and 10% silt and clay:

Selected Sand and Gravel Resource Areas

All the Selected Sand and Gravel Resource Areas are first delineated by geological boundaries and then classified into three levels of significance: primary, secondary and tertiary. Each area of primary significance is given a deposit number and all such deposits are shown by dark red shading on Map 1.

Selected Sand and Gravel Resource Areas of primary significance are not permanent, single land use units. They represent areas in which a major resource is known to exist, and may be reserved wholly or partially for extractive development and/or resource protection.

Deposits of secondary significance are indicated by medium red shading on Map 1. Such deposits are believed to contain significant amounts of sand and gravel. Although deposits of secondary significance are not considered to be the "best" resources in the report area, they may contain large quantities of sand and gravel and should be considered part of the aggregate supply of the area.

Areas of tertiary significance are indicated by light red shading. They are not considered to be important resource areas because of their low available resources, or because of possible difficulties in extraction. Such areas may be useful for local needs but are unlikely to support large-scale development.

The process by which deposits are evaluated and selected involves the consideration of two sets of criteria. The main selection criteria are site specific, related to the characteristics of individual deposits. Factors such as deposit size, aggregate quality, and deposit location and setting are considered in the selection of those deposits best suited for extractive development. A second set of criteria involves the assessment of local aggregate resources in relation to the quality, quantity and distribution of resources in the region in which the report area is located. The intent of such a process of evaluation is to ensure the continuing availability of sufficient resources to meet possible future demands.

SITE SPECIFIC CRITERIA

Deposit Size

Ideally, selected deposits should contain available sand and gravel resources large enough to support a commercial pit operation using a stationary or portable processing plant. In practice, much smaller deposits may be of significant value depending on the overall reserves in the rest of the project area. Generally, deposits in Class 1 (greater than 6 m thick), and containing more than 35% gravel are considered to be most favourable for commercial development. Thinner deposits may be valuable in areas with low total resources.

Aggregate Quality

The limitations of natural aggregates for various uses result from variations in the lithology of the particles composing the deposit, and from variations in the size distribution of these particles.

Four indicators of the quality of aggregate may be included in the deposit symbols. They are: gravel content (G or S), fines (C), oversize (O), and lithology (L).

Three of the quality indicators deal with grain size distribution. The gravel content (G or S) indicates the suitability of aggregate for various uses. Deposits containing at least 35% gravel in addition to a minimum of 20% material greater than the 26.5 mm sieve are considered to be the most favourable extractive sites, since this content is the minimum from which crushed products can be economically produced.

Excess fines (high silt and clay content) may severely limit the potential use of a deposit. Fines content in excess of 10% may impede drainage in road subbase aggregate and render it more susceptible to the effects of frost action. In asphalt aggregate, excess fines hinder the bonding of particles. Deposits known to have a high fines content are indicated by a "C" in the quality portion of the Deposit Symbol.

Deposits containing more than 20% oversize material (greater than 10 cm in diameter) may also have use limitations. The oversize component is unacceptable for all concrete aggregate and for road-building aggregate, so it must be either crushed or removed during processing. Deposits known to have an appreciable oversize component are indicated by an "O" in the quality portion of the Deposit Symbol.

Another indicator of the quality of an aggregate is lithology. Just as the unique physical and chemical properties of bedrock types determine their value for use as crushed rock, so do various lithologies of particles in a sand and gravel deposit determine its suitability for various uses. The presence of objectionable lithologies such as chert, siltstone and shale, even in relatively small amounts, can result in a reduction in the quality of an aggregate, especially for high quality uses such as concrete and asphalt. Similarly, highly weathered, very porous and friable rock can restrict the quality of an aggregate. Deposits known to contain objectionable lithologies are indicated by an "L" in the quality component of the Deposit Symbol.

If the Deposit Symbol shows either "C", "O", or "L" or any combination of these indicators, the quality of the deposit is considered to be reduced for some uses of the aggregate. No attempt is made to quantify the degree of limitation imposed. Assessment of the four indicators is made from published data, from data contained in files of both the Ontario Ministry of Transportation (MTO) and the Sedimentary and Environmental Geoscience Section of the Ontario Geological Survey, and from field observations.

Quality data may also appear in Table 9, where the results of MTO quality tests are listed by test type and sample location. The types of tests conducted and the test specifications are explained in Appendixes B and E, respectively.

Analyses of unprocessed samples obtained from test holes, pits or sample sites are plotted on grain size distribution graphs. On the graphs are the Ontario Ministry of Transportation's gradation specification envelopes for aggregate products: Granular A and Granular B Type I; Hot-Laid Asphaltic Sand nos. 1,2,3,4 and 8; and concrete sand. By plotting the gradation curves with respect to the specification envelopes, it can be determined how well the unprocessed sampled material meets the criteria for each product. These graphs, called Aggregate Grading Curves, follow the tables in the report.

Location and Setting

The location and setting of a resource area has a direct influence on its value for possible extraction. The evaluation of a deposit's setting is made on the basis of natural and man-made features which may limit or prohibit extractive development.

First, the physical context of the deposit is considered. Deposits with some physical constraint on extractive development, such as thick overburden or high water table, are less valuable resource areas because of the difficulties involved in resource recovery. Second, permanent man-made features, such as roads, railways, powerlines and housing developments, which are built on a deposit, may prohibit its extraction. The constraining effect of legally required setbacks surrounding such features is included in the evaluation. A quantitative assessment of these constraints can be made by measurement of their areal extent directly from the topographic maps. The area rendered unavailable by these features is shown for each resource area in Table 3 (Column 3).

The assessment of sand and gravel deposits with respect to local land use and to private land ownership is an important component of the general evaluation process. These aspects of the evaluation process are not considered further in this report, but readers are encouraged to discuss them with personnel of the pertinent District Office of the Ontario Ministry of Natural Resources.

REGIONAL CONSIDERATIONS

In selecting sufficient areas for resource development, it is important to assess both the local and the regional resource base, and to forecast future production and demand patterns.

Some appreciation of future aggregate requirements in an area may be gained by assessing its present production levels and by forecasting future production trends. Such an approach is based on the assumptions that production levels in an area closely reflect the demand and that the present production "market share" of an area will remain roughly at the same level.

The aggregate resources in the region surrounding a project area should be assessed in order to properly evaluate specific resource areas and to adopt optimum resource management plans. For example, an area that has large resources in comparison to its surrounding region constitutes a regionally significant resource area. Areas with high resources in proximity to large demand centres, such as metropolitan areas, are special cases.

Although an appreciation of the regional context is required to develop comprehensive resource management techniques, such detailed evaluation is beyond the scope of this report. The selection of resource areas made in this study is based primarily on geological data or on considerations outlined in preceding sections.

MAP 2: BEDROCK RESOURCES

Map 2 is an interpretative map derived from bedrock geology, drift thickness and bedrock topography maps, water well data from the Ontario Ministry of the Environment, oil and gas well data from the Aggregate and Petroleum Resources Section (Ontario Ministry of Natural Resources) and from geotechnical test hole data from various sources. Map 2 is based on concepts similar to those outlined for Map 1.

The geological boundaries of the Paleozoic bedrock units are shown by a dashed line. The areas of undifferentiated Precambrian bedrock are labelled as such on Map 2. Isolated Paleozoic outcrops are indicated by an "X". Three sets of contour lines delineate areas of less than 1 m of drift, areas of 1 to 8 m of drift, areas of 8 to 15 m of drift and areas of greater than 15 m of drift. The extent of these areas of drift are shown by three shades of blue. The darkest shade indicates where bedrock outcrops or is within 1 m of the ground surface. These areas constitute potential resource areas because of their easy access. The medium to dark shade indicates areas where drift cover is up to 8 m thick. Quarrying is possible in this depth of overburden and these zones also represent potential resource areas. The medium to light shade indicates bedrock areas overlain by 8 to 15 m of overburden. These latter areas constitute resources which have extractive value only in specific circumstances. The light shade indicates bedrock areas overlain by greater than 15 m of drift, a depth generally considered to be too great to allow economic extraction (unless part of the overburden is composed of economically attractive deposits). Outside of these delineated areas are areas of undifferentiated Precambrian bedrock, with varying thicknesses of drift cover.

Other inventory information presented on Map 2 is designed to give an indication of the present level of extractive activity in the report area. Quarries are identified by a number which refers to the descriptions in Table 5. Each description notes an estimate of face height. Two additional symbols may appear on the map. An open dot indicates the location of a selected water well which penetrates bedrock. The overburden thickness is shown in metres beside the open dot. Similarly, test hole locations appear as a point symbol with the depth to bedrock shown in metres beside it. The test holes may be further described in Table 7.

Selection Criteria

Criteria equivalent to those used for sand and gravel deposits are used to select Paleozoic bedrock areas most favourable for extractive development. The areas of Precambrian bedrock are not evaluated in this report.

The evaluation of Paleozoic bedrock resources is made primarily on the basis of performance and suitability data established by laboratory testing at the Ontario Ministry of Transportation. The main charac-

teristics and uses of the bedrock units found in southern Ontario are summarized in Appendix D.

Deposit "size" is related directly to the areal extent of thin drift cover overlying favourable bedrock formations. Since vertical and lateral variations in Paleozoic bedrock units are much more gradual than in sand and gravel deposits, the quality and quantity of the resource are usually consistent over large areas.

Quality of the aggregate derived from specific bedrock units is established by the performance standards previously mentioned. Location and setting criteria and regional considerations are identical to those for sand and gravel deposits.

The Precambrian Shield rocks are generally more complex and variable than the Paleozoic rocks of Ontario. They often show wide variations in mineralogy, texture (grain size), joint patterns and degree of weathering, even within specific rock types and over relatively short distances. As these factors are considered important in determining the suitablity of the bedrock for use as aggregate, the aggregate potential may also vary considerably from location to location.

Careful selection is especially important if the bedrock is to be used as concrete aggregate. Deleterious chemical reactions may develop in the concrete which can lead to its eventual deterioration. Fortunately, these chemical reactions should not influence the use of bedrock–derived aggregate for such uses as roadbase material. However, highly weathered, very porous and friable rock should be avoided for all uses.

For these reasons, no specific Precambrian bedrock resources have been selected for resource protection. A summary of the bedrock resources on a regional level is included in the Bedrock Geology and Resource Potential section.

Selected Resource Areas

Selection of Bedrock Resource Areas has been restricted to a single level of significance. Three factors support this approach. First, quality and quantity variations are gradual. Second, the areal extent of a given quarry operation is much smaller than that of a sand and gravel pit producing an equivalent tonnage of material, and third, since crushed bedrock has a higher unit value than sand and gravel, longer haul distances can be considered. These factors allow the identification of alternative sites having similar development potential. The Selected Areas, if present, are shown on Map 2 by a line pattern and the calculated available tonnages are given in Table 6.

Selected Bedrock Resource Areas shown on Map 2 are not permanent, single land use units. They represent areas in which a major bedrock resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection.

Part III — Assessment of Aggregate Resources in Laxton, Digby and Longford and Dalton Townships

LOCATION AND POPULATION

The report area occupies 63 504 ha in the northern part of Victoria County. It consists of Dalton Township Municipality and Laxton, Digby and Longford Township Municipality, which was formed through the amalgamation of Longford, Digby and Laxton geographic townships. Population centres within the area include the communities of Norland and Sebright which are located along the area's eastern and western borders, respectively. The area is covered by the Fenelon Falls (31 D/10), Gravenhurst (31 D/14), Minden (31 D/15) and Orillia (31 D/11) map sheets of the National Topographic System, at a scale of 1:50 000.

The population of the area was 1319 in 1991 (Ontario Ministry of Municipal Affairs 1992). Most of this population is concentrated in Laxton geographic township and southern Dalton Township. A well developed road network, including King's Highway 35 and Secondary Highway 503, has been developed in these southern areas. Digby and Longford geographic townships and northern Dalton Township are predominantly wilderness and much of this area is poorly accessible.

PHYSIOGRAPHY AND SURFICIAL GEOLOGY

The terrain in the report area has been divided into two physiographic regions by Chapman and Putnam (1984). Most of Dalton, Longford and Digby geographic townships are included in the Georgian Bay fringe. This area is characterized by a thin drift cover and bare Precambrian bedrock knobs and ridges. The other physiographic region, the Carden plain, predominates in Laxton geographic township. In this region, the limestone bedrock is covered by a thin layer of overburden with some areas of thicker accumulations.

The glacial features in the report area are related to the last major advance and melting of a continental ice sheet during the Late Wisconsinan Substage of the Pleistocene Epoch (informally known as the "Great Ice Age"). During this substage, glacial ice advanced in a southwesterly direction across the area (Deane 1950; Sharpe 1978; Finamore and Bajc 1983, 1984; Bajc and Paterson 1992). As the ice retreated from the area, numerous glacial features consisting of sand and gravel were deposited. These include subaqueous fans, outwash, glaciolacustrine plains, glaciolacustrine deltas, glaciolacustrine beaches, an esker and ice-contact stratified drift deposits.

During glacial retreat from the area, a proglacial lake formed in the low-lying areas between the ice to the north and higher ground to the south. The major sand and gravel features in Dalton Township and Laxton geographic township were deposited in these glacial lake waters. Most of the sand and gravel in the area is concentrated in two northeast-striking ice-contact – subaqueous fan systems in Dalton Township and Laxton geographic township. The system in Dalton Township extends from the northern boundary of the township southwest to Young Lake, a distance of 11 km. The system situated along the eastern boundary of Laxton geographic township is also about 11 km in length. The material in these two systems was deposited within meltwater conduits in the glacial ice or as subaqueous fans where sediment-laden meltwaters were discharged from the conduits into glacial lake waters. Typically, the deposits consist of fine to coarse sand with localized areas underlain by fine to coarse gravel. Gravel tends to be concentrated either in high-relief ridges or at depth within the deposits. Silt seams and an upper layer of 1 to 2 m of silty fine sand are common in some pit exposures. A variable fines content is the major factor influencing aggregate quality within the deposits. Products ranging from crushed gravel to Select Subgrade Material (SSM) have been produced from pits developed in both of these systems. Glaciolacustrine deposits are abundant along the course of the Black River, however, the sand is too fine for most aggregate uses except fill. Many of the remaining granular deposits in the townships are small, isolated bodies of ice-contact, outwash, subaqueous fan, esker, glaciolacustrine delta or glaciolacustrine beach material that may be suitable for small-scale pit development for the extraction of low-specification aggregate.

Since the disappearance of the ice sheet and lowering of lake waters to present-day levels, organic deposits have developed in depressions in the land surface and alluvium has been laid down along the courses of creeks and rivers, particularly the Black River. The high fines content of alluvium usually makes it unsuitable for aggregate use.

EXTRACTIVE ACTIVITY

Numerous sand and gravel pits have been opened in the report area. The pits are typically small operations capable of meeting some local demands for low-specification aggregate and minor amounts of high-specification aggregate. Most of the area's demand for high quality aggregate is being met by importing crushed stone from outside the township.

There are 5 limestone quarries in the report area, all of which are located in southeastern Laxton geographic township. Four of the quarries are either active or inactive sources of flagstone. The fifth quarry has been abandoned. There is also one quarry under development in the Precambrian bedrock.

SELECTED SAND AND GRAVEL RESOURCE AREAS

Map 1 indicates the deposits which contain granular materials. These deposits occupy a total of approximately 4500 ha and contain an original resource tonnage of 146 million tonnes. Many of these deposits have limited potential for extraction because of the restricted amount of aggregate, poor quality of the aggregate and/or poor resource accessibility. Consequently, only the most significant sources have been suggested for possible resource protection.

The deposits selected at the primary level of significance have been grouped into 3 Selected Sand and Gravel Resource Areas. The deposits contain aggregate resources considered suitable for the production of road subbase, SSM and minor amounts of crushed gravel. Many deposits have also been selected at the secondary level of significance. These deposits tend to be somewhat more limited with respect to aggregate potential when compared to the primary selections, but are still considered to be valuable potential sources of local aggregates.

The Selected Sand and Gravel Resource Areas of primary significance occupy a total area of 620 ha. Cultural constraints and previous extraction reduce the area currently available to 415 ha. The areas contain possible sand and gravel resources of approximately 35.4 million tonnes.

Selected Sand and Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 is located in eastern Laxton geographic township and is designated as Areas 1a to 1d on Map 1. This Resource Area consists of a series of gently sloping, northeast-trending ridges of ice-contact – subaqueous fan origin.

Pit faces in these deposits revealed material typical of ice-contact – subaqueous fans. The aggregate tends to become finer towards the surface and flanks of the deposits. Three different sediment types are common within the deposits. One type is silty fine to medium sand which may contain frequent silt seams. This material was common in the upper levels of the pit faces and generally increased in thickness away from the cores of the deposits. The upper 3 and 1.5 m in pit nos. 16 and 23, respectively, and most of the faces in pit nos. 17, 18, 19 and 25 consisted of this fine aggregate. The second sediment type is sandy gravel and gravelly sand with between 15 and 45% fine gravel. This aggregate typically underlies varying thicknesses of the silty fine to medium sand. Faces in pit no. 15 and the lower levels of pit nos. 16 and 23 consisted of this material. The third type is fine to coarse gravel containing between 50 and 70% gravel. This coarse aggregate often occurred at depth within the deposits and occasionally near the surface. Pockets of coarse gravel have been extracted from below the water table in the floors of pit nos. 18, 19, 24 and 25 and from the floor of pit no. 15. The thickness of the first two material types above the coarser aggregate ranged from 2.4 to 7.6 m in these pits. Faces in pit no. 20 consisted entirely of fine to coarse gravel. Pockets of fine to coarse gravel also existed in pit nos. 29 and 30 which are located in the thinner parts of the deposits.

The gravel in Resource Area 1 consisted predominately of Precambrian bedrock clasts with the exception of Area 1d and the southern tip of Area 1c which also contained Paleozoic clasts. Abundant clasts of the Paleozoic-aged Shadow Lake Formation, observed in pit no. 30, may limit the use of the aggregate for some products.

The deposits are considered to be valuable potential sources of aggregate in an area lacking sand and gravel deposits. Aggregate products produced from the Resource Area are dependent on the type of material present. The silty sand is generally suitable for low-grade sand uses such as SSM. Sections that contain excessive silt seams should be avoided. Pit-run granular subbase can potentially be produced from the gravelly sand and sandy gravel. A sample taken of this material from pit no. 15 appears well suited for Granular B Type I (Figure 3a). The fine to coarse gravel is potentially suitable for the production of crushed gravel for use in Granular A and hot-laid asphaltic stone. Where this coarse material occurs as pockets within finer aggregate, selective extraction and sand control may be necessary for crushing. Sections consisting predominantly of this coarse aggregate, as in pit no. 20, exhibit the greatest potential for crushing. A sample of the aggregate from pit no. 20 appears well suited for the production of Granular A and M (Figure 3a). In general, the Resource Area is considered predominantly a source of pit-run aggregates suitable for SSM and Granular B subbase, however, limited amounts of crushable gravel are available. Additional resources of fine to coarse gravel may be discovered by concentrating subsurface exploration below the crest of the ridge along the central part of the deposit. Also, the gravel tends to be closer to the surface in areas where the underlying bedrock is relatively close to the surface.

Resource Area 1 occupies 295 ha of which approximately 169 ha are currently available for extraction. Assuming average deposit thicknesses ranging from 2.4 to 5.5 m, sand and gravel resources are estimated to total 15 million tonnes. Access to the area is provided by King's Highway 35, Secondary Highway 503 and township roads.

Selected Sand and Gravel Resource Area 2

Ice-contact – subaqueous fan deposits in western Dalton Township have been designated as Selected Sand and Gravel Resource Areas 2a to 2g. The Resource Area consists of a series of gently sloping northeast-trending ridges with the exception of Area 2d which

forms a prominent ridge which rises over 6 m above the surrounding terrain.

The area consists of similar materials to that previously described for Resource Area 1. Descriptions of the three different material types observed in Resource Area 1 also apply to Resource Area 2. Silty fine to medium sand is the predominant material exposed in pit nos. 41, 43, 45 and 46. Sandy gravel and gravelly sand has been extracted from pit nos. 37 and 44 and from below the water table in the floor of pit no. 43. Pit nos. 36 and 42 contained pockets of fine to coarse gravel. Pit faces ranged in height from 1.5 to 9.1 m within the resource area.

Resource Area 2 is the major potential aggregate source in Dalton Township. As in Resource Area 1, the aggregate quality varies depending on the type of materials present. The silty sand is generally suitable only for low-specification sand uses including SSM and blending sand. Sections which contain excessive quantities of silt should be avoided. The gravelly sand to sandy gravel appears well suited for granular subbase. Crushed gravel may be produced with selective extraction of coarse gravel pockets. Samples taken of this material from pit nos. 36 and 42 contained hard and durable aggregate which met MTO quality criteria for products including hot-laid asphaltic stone products and Granular A (Figure 4a). Overall, the resource area is primarily a potential source of sandy aggregate suitable for granular subbase and low-specification sand products. Similar to Resource Area 1, the parts of the deposits with the highest elevations, usually the central portions of the features, may have the highest potential for containing coarse aggregate at depth. The prominent ridge which forms Area 2d is one such high potential area.

Approximately 220 ha are currently available for extraction in Resource Area 2. The average thickness of each deposit is either 4.6 or 6.1 m, thus, sand and gravel resources are estimated to total 18.6 million tonnes. Some of the deposits are accessible by township roads, others have limited access.

Selected Sand and Gravel Resource Area 3

Selected Sand and Gravel Resource Area 3 consists of two subaqueous fan deposits located in northeastern Dalton Township. The pits identified in Area 3 have been developed in areas where higher concentrations of gravel are exposed at the surface. Fine to medium sand is the predominant material exposed at the surface away from the pits. Pit nos. 34 and 35 revealed sandy gravel and gravelly sand with an estimated 30 to 40% gravel. The gravel in pit no. 33 is concentrated in pockets within sandy aggregate and gravel contents vary from 10 to 50%. Faces in the pits ranged from 1.5 to 3.0 m and bedrock is exposed in the floor of pit no. 33.

Pit nos. 34 and 35 contain aggregates that are well suited for production of Granular B Type I, whereas, selective extraction of the more gravelly units may be necessary for production of granular subbase from pit no. 33. Further subsurface investigation is required to determine if similar aggregate to that exposed in the pits underlies the undeveloped parts of the resource area.

The deposits of Resource Area 3 cover approximately 36 ha of which 27 ha are currently available for extraction. Assuming an average deposit thickness of 3.7 m, the aggregate resources total 1.8 million tonnes. A gravel road provides access to the area.

Resource Areas of Secondary Significance

Four outwash-glaciolacustrine and outwash deposits in the northern half of Longford geographic township have been selected as sites of secondary significance. Pit nos. 3 and 4 in the north-central area revealed aggregate suitable for granular subbase. A sample taken from pit no. 4 met quality criteria for Granular B Type I (Figure 3a). The faces of pit no. 6, in the deposit further south, revealed 1.5 m of medium sand to sandy fine gravel. The material in this deposit appears suitable for use on local cottage and forest-access roads. The undeveloped deposit in the northwestern corner is considered to be a potential source of pit-run sand. Additional subsurface information would be required to determine the nature of the materials at depth.

Three ice-contact features in southern Longford and northern Digby geographic townships have been selected as areas of secondary significance. Two pits have been opened in these deposits. The 1.5 to 2.1 m faces in pit nos. 7 and 10 exposed fine silty sand to fine gravel. Augering in the undeveloped areas uncovered 1 m of gravelly sand to coarse gravel. The deposits are well suited for the extraction of granular subbase.

Three subaqueous fan deposits in the report area are designated as secondary resources. Two deposits in southeastern Dalton Township contain pit nos. 47, 48 and 49. The 0.9 to 2.4 m faces of these pits revealed a variety of sediments ranging from fine sand to coarse gravel. The deposits are primarily sources of sand suitable for use as SSM. In these deposits, consideration must be given to the possible presence of frequent silt seams and a high water table. Similar to other subaqueous fans in the report area, there is potential for encountering gravel at depth. These coarser units may also occur close to bedrock outcrops, as is the situation in pit nos. 47 and 48. The third subaqueous fan, in the northeast corner of Laxton geographic township, contains pit no. 14. The 3.0 to 3.6 m faces of this pit exposed only silty fine to medium sand, suitable for pit-run aggregate.

Also selected as secondary resources are 3 subaqueous fan-glaciolacustrine plain deposits, two are located in southwest Dalton Township and one is located in southeast Laxton geographic township. Fine to me-

dium sand is exposed at the surface of the two undeveloped deposits and sand is revealed in the 0.9 to 1.5 m faces of pit no. 26, in southeast Laxton geographic township. The deposits are primarily sources of sand suitable for low-specification sand products, however, localized pockets of gravel may be encountered at depth within the southeastern deposit.

An esker in southwestern Laxton geographic township has also been designated a resource of secondary significance. A 1 m deep test pit, excavated into the crest of this 1.5 to 3 m high ridge, uncovered slightly dirty, coarse gravel with abundant oversize particles. This feature appears suitable for small-scale pit development for the extraction of low-specification granular products for local use.

The last 4 secondary resource areas are ice-contact – subaqueous fan deposits located in western Dalton Township. Subsurface data are lacking for these deposits, although fine to medium sand is exposed at the surface of all of the deposits. Bedrock may be encountered close to the surface in some areas of the deposits, this may be a problem particularly in the northernmost deposit. These deposits are considered to be potential sources of low-grade sand products. Detailed subsurface investigation is recommended prior to extractive development.

BEDROCK GEOLOGY AND RESOURCE POTENTIAL

The oldest bedrock within the townships are Precambrian-aged rocks of the Central Gneiss Belt and Central Metasedimentary Belt Boundary Zone of the Canadian Shield (Wynne-Edwards 1972; Easton 1988). These metamorphic and igneous rocks underlie the majority of the report area. Geological mapping by Easton et al. (1985a and 1985b), Easton, Van Kranendonk and Yong (1987), Easton (1988) and the Ontario Geological Survey (1991) cover the area. The Precambrian rocks consist predominantly of felsic igneous rocks, gneisses and migmatitic rocks with minor anorthosite, tectonite and carbonate metasediments. The bedrock geology of the area is portrayed at a reconnaissance level in Figure 2.

The Precambrian bedrock may exhibit wide variations with respect to aggregate quality over relatively short distances. Consequently, any site proposed for quarry development should be tested in detail before extraction occurs. Highly weathered, brittle and friable Precambrian bedrock, which is unacceptable for aggregate use, may occur within the report area. There are also many areas underlain by more massive, hard and durable rock which appears suitable for a variety of aggregate applications. However, some of the massive, coarse-grained felsic igneous rocks and gneisses with high mica, feldspar and quartz contents may have bonding problems because the smooth cleavage and fracture surfaces of these minerals hinder the adhesion of asphalt and cement mixes. This problem may be circumvented by weathering the rocks for a period of time in stockpiles or by adding chemicals (anti-stripping agents) which erode the smooth surfaces and allow better adhesion. Rogers (1985) reports that some granitic rocks can slowly react with the alkalies from Portland cement concrete, resulting in concrete deterioration.

Although the Precambrian bedrock in the area may meet MTO specifications for concrete aggregate, it may not be accepted by MTO for use in Portland cement concrete which will be exposed to de-icing salts. There could be a potential bonding problem between the aggregate and cement.

There is one Precambrian rock quarry under development in Laxton geographic township. No specific areas of Precambrian bedrock have been selected for possible resource protection because Paleozoic bedrock is considered the preferred source of bedrock-derived aggregates in the area. The Precambrian rock is generally more variable and difficult to process than the Paleozoic strata. There is one quarry under development in Laxton geographic township. If large scale road-building or construction projects are undertaken in the northern part of the report area, the Precambrian bedrock should be considered as a potential aggregate source. There is considerable latitude for choosing sites for extraction of Precambrian rock as bedrock is close to the surface through much of the northern area.

During the Paleozoic Era, a succession of sedimentary rocks were deposited in the shallow seas which covered the area. These rocks underlie much of Laxton geographic township and the southern parts of Dalton Township and Digby geographic township. The oldest Paleozoic bedrock exposed in the townships, the Shadow Lake Formation, was deposited in nearshore environments over an undulating Precambrian surface. The Shadow Lake Formation shales, siltstones, sandstones and conglomerates are overlain by limestones and dolostones of the Gull River Formation and limestones of the Bobcaygeon Formation. Recent lithostratigraphic revisions by Williams (1991) have reassigned the upper part of the Gull River Formation to the Bobcaygeon Formation. The formation contacts shown on Map 2, however, have been based on previous work (Caley and Liberty 1950, 1952; Liberty 1969), as mapping using the revised contacts is currently unavailable.

Of the Paleozoic rock formations which underlie the townships, the Gull River and Bobcaygeon formations are the best suited for aggregate extraction (Derry Michener Booth and Wahl and Ontario Geological Survey 1989a, 1989b). The soft and friable shales, siltstones, sandstones and conglomerates of the Shadow Lake Formation are unsuitable for most aggregate uses.

Crushed stone from the Gull River Formation is extracted for a variety of aggregate uses in southern Ontario, including concrete, asphalt and granular base. Testing of the rock is necessary because certain beds within the formation are chemically reactive with Port-

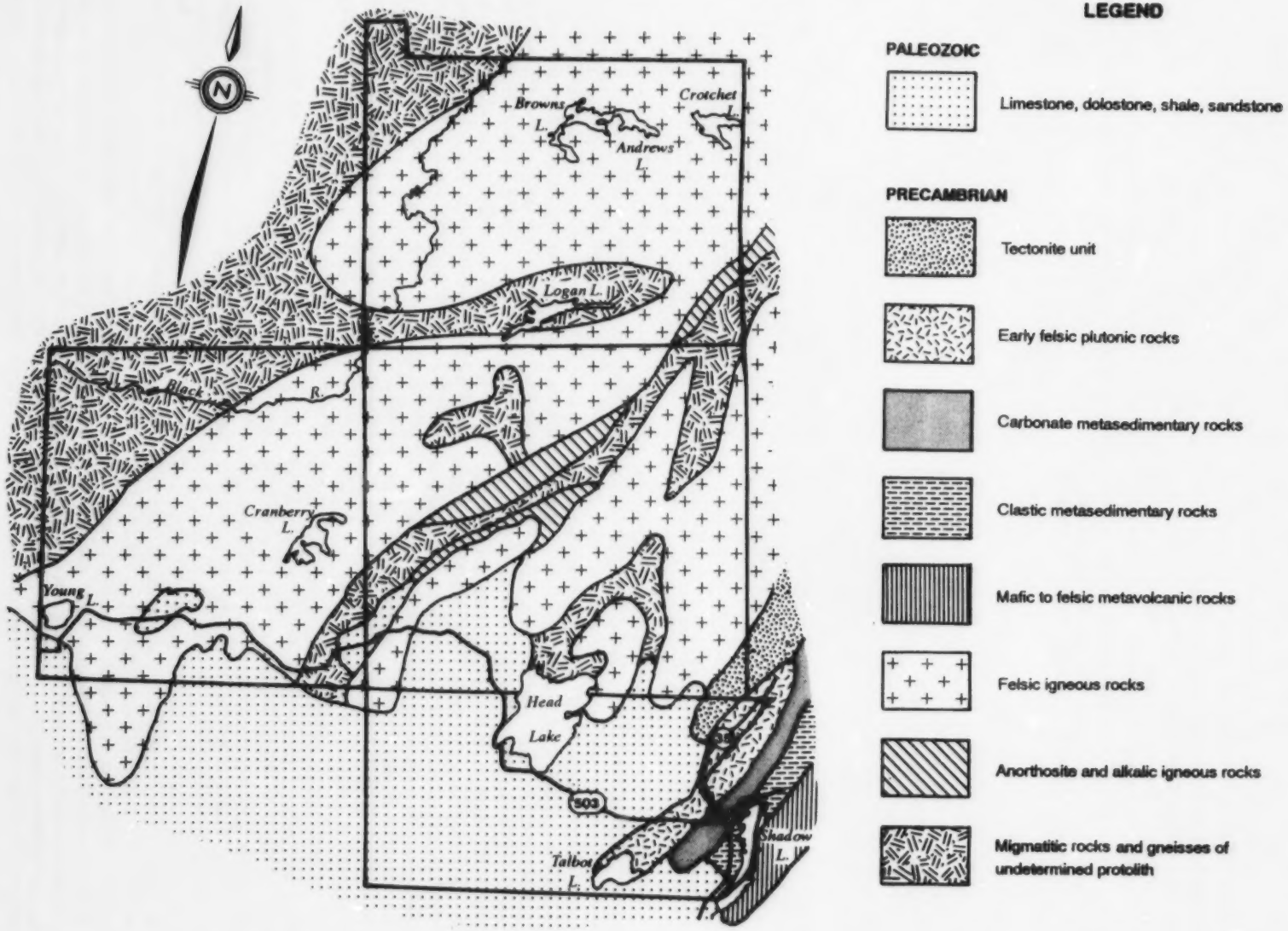


Figure 2. Bedrock geology of Laxton, Digby and Longford and Dalton townships, scale 1:240 000 [*after* Ontario Geological Survey (1991)]

land cement mixes (Rogers 1985). This reaction, an alkali-carbonate reaction, can result in the deterioration of concrete structures subject to moist environments and/or road salts. Alkali-carbonate reactive beds cannot be readily identified through visual examination in the field. They can be identified by subjecting the rock to concrete expansion testing, microscopic examination and/or chemical analysis (Rogers 1985). Selective extraction of the nonreactive beds may, therefore, be required for production of some concrete aggregates. The Gull River Formation bedrock is generally well suited for use as hot-laid asphalt, but polishing of the stone may be a problem if the rock is used in asphaltic surface course. Beds of shaly, silty to sandy dolostone may require blending with the surrounding, more competent, bedrock units for the production of granular base. Similarly, beds of calcitic dolostone at the base of the formation may only be suitable for granular base.

Similar to the Gull River Formation bedrock, certain beds within the Bobcaygeon Formation may be alkali-reactive. In this case, an alkali-silicate reaction occurs between Portland cement concrete and the silica-bearing rocks. Beds within the Bobcaygeon Formation found to be reactive usually contain less than 3% black chert along with microscopic chalcedony (Rogers 1985). The more shaly, middle parts of the formation may not be as suitable for the production of concrete aggregates as the surrounding strata (D. Williams, personal communication 1991). Therefore, selective extraction measures may be required for the production of concrete aggregates within the formation. The formation is generally well suited for most other aggregate uses including asphaltic stone and granular base.

Most of the areas underlain by the Gull River and Bobcaygeon formations and covered by less than 8 m of drift have been selected as Bedrock Resource Areas. Bedrock identified as Shadow Lake Formation or Shadow Lake and Gull River formations has not been selected for possible resource protection. As well, the Gull River Formation limestone, in an outlier at Uphill, has not been selected since the limestone in that area is expected to be relatively thin. The Selected Bedrock Resource Areas occupy a total available area of 7600 ha and contain resources of 3600 million tonnes.

Selected Bedrock Resource Area 1

Selected Bedrock Resource Area 1 is located in Laxton and southern Digby geographic townships and southern Dalton Township. This Resource Area consists of most of the areas of the Gull River Formation that are overlain by approximately 0 to 8 m of drift.

Five quarries have been opened in Area 1. In quarry nos. 1 to 4, thin beds of limestone have been extracted for use as flagstone. Gull River Formation bedrock has also been extracted from the 3.0 to 3.7 m high faces of abandoned quarry no. 5. Steep escarpments ranging in height from 7 to over 15 m often mark the contact of the Paleozoic with the Precambrian rock. In these escarpments, between 3 and 15 m of the Gull River Formation strata may overlie the Shadow Lake Formation. Away from the escarpment, the Gull River Formation generally increases in thickness in a southwesterly direction to about 24 m near the Bobcaygeon-Gull River Formation boundary. The formation thickness boundary shown on Map 2 generally indicates where the formation thickness is estimated to be roughly 12 m. This boundary has been based on information provided by water wells, bedrock exposures and topographic expression. Between the Paleozoic escarpments and the thickness boundary, the Gull River Formation limestone is expected to be less than 12 m, whereas the likelihood of the limestone being greater than 12 m increases between the thickness boundary and the Bobcaygeon Formation. The thickness of the Gull River Formation around Brush Lake and in the swampy terrain to the north has not been determined and further testing in the area is strongly recommended to determine the exact nature of the bedrock.

The Gull River Formation represents a potential source of concrete, asphaltic and granular base aggregates. Selective extraction is required for the production of aggregate for concrete and hot-laid asphalt. The area of the Gull River Formation that is located between the formation thickness boundary and the Bobcaygeon Formation limestone and is overlain by less than 1 m of drift may offer the highest potential for extractive development within Resource Area 1.

Selected Bedrock Resource Area 1 occupies 5600 ha of which 4650 ha are available for extraction. Although the thickness of the Gull River Formation strata can vary from less than 3 to 24 m, the tonnage values have been calculated using a thickness of 18 m which is considered the average thickness of the formation in Area 1. Available bedrock resources are estimated to be approximately 2220 million tonnes in Resource Area 1. The area is accessible by Secondary Highway 503 and township roads.

Selected Bedrock Resource Area 2

Selected Bedrock Resource Area 2 is located in Laxton and southern Digby geographic townships and southern Dalton Township. This Resource Area consists of areas of the Bobcaygeon Formation that have an overlying drift thickness of 0 to 8 m. At present, there are no quarries opened in this Resource Area. The limestone of the Bobcaygeon Formation can be as much as 24 m thick in the region (Liberty 1969) and the thickness generally increases towards the southwest, away from the Bobcaygeon-Gull River Formation boundary. In areas close to the boundary, it may be possible to extract the underlying Gull River Formation strata along with the Bobcaygeon Formation limestone.

The Bobcaygeon Formation is generally suitable for uses including hot-laid asphalt, granular base and surface treatment aggregates. Selective extraction may be required for the production of concrete aggregate. Those areas overlain by less than 1 m of drift are consid-

ered to have the highest potential within Resource Area 2.

Selected Bedrock Resource Area 2 occupies 3200 ha of which 2900 ha are available for extraction. Assuming an average bedrock thickness of 18 m, available resources are estimated to be approximately 1400 million tonnes. Access to Resource Area 1 is possible via Secondary Highway 503, as well as, township roads.

AGGREGATE QUALITY AND SUITABILITY

In general, the gravel in the report area is considered to be of sufficient quality for uses including Granular A, B Type I and M. The results of the quality testing performed on 5 samples taken from the area, for the most part fall within the Ontario Ministry of Transportation's (MTO) specification limits for these granular products (Table 9). Higher specification uses of the aggregate may, however, be limited in some localities by the presence of friable and brittle gneissic particles within the gravel. The brittle and friable particles are largely responsible for the high hot mix and concrete petrographic numbers given by local aggregates.

The local aggregates, however, perform well in asphalt pavements in the field. Consequently, MTO has modified the maximum petrographic number allowed in Hot-Laid (HL) No. 4 aggregate, increasing the number to 180 from 160. Similarly, the Los Angeles Abrasion and impact losses have been modified to permit a loss of up to 50% in aggregates from the area, instead of the usual 35% (Rogers 1985). Although specifications have been modified, two samples still do not meet criteria for use as HL No. 4 asphaltic stone.

Although an aggregate may meet specifications, the local gravels are not accepted by MTO for use in Portland cement concrete which will be exposed to deicing salts. There can be a bonding problem between the cement and gravel which results in spalling of the concrete.

The specification modifications, noted above, and concrete acceptance problem apply only to gravels consisting primarily of Precambrian clasts. Aggregates from those deposits containing a high proportion of Paleozoic clasts (Resource Areas 1c and 1d) must meet standard MTO criteria. Those deposits, however, contain a high proportion of soft and friable clasts from the Shadow Lake Formation which may limit high-specification aggregate uses.

SUMMARY

The sand and gravel deposits in the report area are the product of glacial activity which occurred during the Late Wisconsinan Substage of the Pleistocene Epoch. A number of these deposits, which contain significant resources of sand and gravel, have been grouped together into 3 primary Resource Areas. In addition, numerous deposits of secondary significance, which add to the area's resource base, have been selected. Care should be taken to ensure the continued availability of as much of the resource areas as possible.

In general, the townships contain only limited sand and gravel resources. Most of the aggregate resources are concentrated in 3 systems of ice-contact and/or subaqueous fan deposits in Dalton Township and Laxton geographic township. These systems contain relatively abundant resources of sandy aggregate, suitable for uses including road subbase and SSM, and only minor amounts of crushable gravel. Outside these 3 systems, bedrock terrain predominates with only small isolated bodies of sand and gravel available for extraction. A considerable proportion of the area's demand for high-specification aggregate is supplied by importing crushed stone from outside the township.

Paleozoic-aged limestones are the major potential sources of high quality, crushed stone within the townships. These resources lie predominantly within two Selected Bedrock Resource Areas in the southern parts of the resource area. The Resource Areas consist of rock of the Gull River and Bobcaygeon formations. These rocks are suitable for a wide range of aggregate applications. Elsewhere in the area, hard and durable varieties of Precambrian bedrock are alternate potential sources of crushed stone.

Enquiries regarding the Aggregate Resources of Laxton, Digby and Longford and Dalton Townships should be directed to the Sedimentary and Environmental Geoscience Section, Ontario Geological Survey, Ministry of Northern Development and Mines, 7th Floor, 933 Ramsey Lake Road, Sudbury, Ontario, P3E 6B5 [Tel. (705) 670-5904] or to the Resident Geologist, Ministry of Northern Development and Mines, P.O. Box 190, Dorset, Ontario, P0A 1E0 [Tel. (705) 766-2494] or to the Resident Geologist, Ministry of Northern Development and Mines, Bag Service 43, Old Troy Road, Tweed, Ontario, K0K 3J0 [Tel. (613) 478-3161] or to the Mineral Resources Staff, Ontario Ministry of Natural Resources, Minden, Ontario, K0M 2K0 [Tel. (705) 286-1521] or to the Mineral Resources Staff, Ontario Ministry of Natural Resources, 322 Kent Street West, Lindsay, Ontario, K9V 4T7 [Tel. (705) 324-6121].

TABLE 1. TOTAL SAND AND GRAVEL RESOURCES, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

1 CLASS NO.	2 DEPOSIT TYPE (*see* Appendix C)	3 AREAL EXTENT Hectares	4 ORIGINAL TONNAGE Millions of Tonnes
Longford Geographic Township			
2	S–OW–LP	32	2.1
3	G–IC	3	0.1
	G–OW	4	0.1
	G–OW–LP	4	0.2
	S–IC	8	0.3
	S–IC–LD	10	0.4
	S–OW–LP	44	1.8
4	G–OW–LP	4	<0.1
	S–AL	300	6.5
	S–IC	3	<0.1
	S–LP	540	11.6
	S–OW–LP	124	2.7
		1080	25.8
Digby Geographic Township			
3	G–IC	3	0.1
4	G–LB	4	<0.1
	S–LP	100	2.2
		107	2.3
Laxton Geographic Township			
2	S–IC–SF	285	25.7
	S–SF	6	0.4
3	G–E	16	0.5
	G–IC–SF	11	0.5
	S–LP	3	0.1
	S–SF	18	0.8
	S–SF–LP	44	1.9
4	G–IC	4	<0.1
	G–IC–SF	4	<0.1
	S–LP	1080	23.3
		1470	53.2
Dalton Township Municipality			
1	G–IC	6	0.6
	S–IC–SF	31	3.3
2	S–IC–SF	260	20.7
	S–SF	36	2.3
3	S–IC–SF	87	3.5
	S–LP	131	5.7
	S–LP–SF	26	1.1
	S–OW–LP	6	0.1
	S–SF	18	0.6
4	G–LB	10	0.2
	S–IC–SF	18	0.4
	S–LP	1180	25.5
	S–SF	24	0.6
		1830	64.6
TOTAL FOR REPORT AREA:		4500	146

N.B. Minor variations in all tables are caused by rounding of data.

TABLE 2. SAND AND GRAVEL PITS, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

1 NO.	2 FACE HEIGHT Metres	3 % GRAVEL	4 REMARKS
Longford Geographic Township			
1	0.9–1.2	0	fine to medium sand flanking rock
2	0.9	0	medium sand, water on pit floor
3	4.6	15	1.2 m of fine to coarse gravel over 0.3 m of silty fine sand over 3.0 m of medium sand
4	2.4	50–60	sandy fine gravel
5	–	–	partially rehabilitated
6	1.5	10–50	ranges from medium sand to sandy fine gravel
7	1.5–2.1	0–30	variable material ranging from silty fine sand to fine gravel
8	0.9	30	gravelly medium to coarse sand which becomes finer at depth
9	0.9–1.5	0–5	clean medium sand
Digby Geographic Township			
10	1.5	30–40	0.6 to 0.9 m of fine gravel over clean medium sand
11	1.2	0	medium sand, water on pit floor
Laxton Geographic Township			
12	1.2	–	gravel, overgrown, bedrock exposed in pit floor
13	3.0–4.6	50–60	variable material, oversize clasts present
14	3.0–3.6	0	silty fine to medium sand
15	2.4–4.6	30–45	freshly worked face exposed 0.9 m of gravelly medium sand over 0.9 m of fine gravel over 0.6 m of coarse sand, bedrock exposed in pit floor
16	3.0–6.1	0–25	3.0 m of silty fine sand with some silt lenses over fine gravelly sand
17	1.5–2.4	0	overgrown
18	1.5–6.1	<20	fine to medium sand with minor pockets of gravelly sand, silt seams present, coarse gravel was removed from below water table, bedrock in one face
19	6.1–7.6	<20	same as pit no. 17
20	6.1	50–60	fine to coarse gravel, bedrock exposed in one area of the pit floor
21	1.5	0	fine silty sand
22	1.5	<5	silty, fine to medium sand
23	4.6	10–25	1.5 m of silty fine to medium sand over 3.0 m of medium to coarse sand with variable amounts of fine gravel
24	2.4–3.0	40	sandy fine to coarse gravel, some coarse gravel extracted from below the water table
25	2.4–4.6	–	silty fine to medium sand, some coarse gravel extracted from below the water table
26	0.9–1.5	0	sand, overgrown
27	3.0–4.6	–	overgrown, water on pit floor
28	7.6	–	rehabilitated
29	1.5–2.4	30–50	overgrown
30	1.5–2.4	40–50	variable material, abundant clasts of poor quality Shadow Lake Formation
31	1.2	10–40	gravelly fine to coarse sand, water on pit floor, overgrown
32	6.0–7.5	variable	mainly silty fine to medium sand, clay in pit floor, <1 m thick layer of coarse gravel at surface

TABLE 2. SAND AND GRAVEL PITS, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

1 NO.	2 FACE HEIGHT Metres	3 % GRAVEL	4 REMARKS
Dalton Township Municipality			
33	1.5–3.0	10–50	variable from fine gravel to fine sand with silt seams, bedrock exposed in pit floor
34	1.5	30–40	1.5 m of gravelly sand, medium sand in pit floor
35	2.4	40	0.6 to 1.2 m of fine to coarse gravel over gravelly sand
36	4.6	30–65	variable from sand to coarse gravel
37	2.4	35–45	sandy fine gravel
38	3.6	20	gravelly fine to medium sand
39	1.2	60–70	fine gravel
40	3.0	10–30	0.9 to 1.5 m of silty fine to medium sand over steeply inclined layers of gravelly sand
41	3.0	0	slumped sand
42	3.0–6.1	20–70	variable material ranging from 4.6 m pockets of coarse gravel to silty fine sand
43	3.0	0–30	1.2 m of silt and silty fine sand over fine to medium sand, gravel below water table
44	1.5	30	coarse sand and fine gravel
45	9.1	0–15	predominantly fine to medium sand, minor pockets of fine gravel
46	3.0–5.5	0–5	fine to medium sand, silt seams, gravel once extracted from below water table
47	1.5–2.4	0	fine sand with a 0.3 m thick silt seam present
48	0.9–1.5	10–30	varies from medium to coarse sand to gravel, bedrock in pit floor
49	0.9–1.5	20	coarse gravel over coarse sand, bedrock in pit floor
50	1.5–2.4	60–70	tabular beach gravel over bedrock, oversize clasts present

TABLE 3. SELECTED SAND AND GRAVEL RESOURCE AREAS, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

1 DEPOSIT NO.	2 AREA Hectares	3 CULTURAL SETBACKS Hectares	4 EXTRACTED AREA Hectares	5 AVAILABLE AREA Hectares	6 ESTIMATED DEPOSIT THICKNESS Metres	7 AVAILABLE AGGREGATE Millions of Tonnes
Longford Geographic Township						
			– none –			
Digby Geographic Township						
			– none –			
Laxton Geographic Township						
1a	222	85	10	127	5.5	12.4
1b	20	2	2	16	3.7	1.0
1c	44	17	5	22	3.7	1.4
1d	11	2	5	14	2.4	0.2
	295	106	22	169		15.0
Dalton Township Municipality						
2a	27	7	1	19	4.6	1.5
2b	28	0	1	27	4.6	2.2
2c	47	11	1	35	4.6	2.8
2d	6	0	1	5	6.1	0.5
2e	3	0	0	3	6.1	0.3
2f	145	33	2	110	4.6	9.0
2g	28	3	4	21	6.1	2.3
	285	54	10	220		18.6
3a	22	3	1	18	3.7	1.2
3b	14	5	0	19	3.7	0.6
	36	8	1	27		1.8
TOTAL FOR REPORT AREA:	620	168	33	415		35.4

TABLE 4. TOTAL IDENTIFIED BEDROCK RESOURCES, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

1 DRIFT THICKNESS Metres	2 FORMATION	3 ESTIMATED DEPOSIT THICKNESS Metres	4 AREAL EXTENT Hectares	5 ORIGINAL TONNAGE Millions of Tonnes
Longford Geographic Township				
		– none –		
Digby Geographic Township				
1–8	Shadow Lake	3	97	8
0–1	Gull River	18	480	229
1–8	Gull River	18	710	340
			1190	570
0–1	Bobcaygeon	18	7	3
			1290	580
Laxton Geographic Township				
1–8	Shadow Lake	18	58	28
0–1	Gull River	18	3300	1570
1–8	Gull River	18	950	455
			4250	2020
0–1	Bobcaygeon	18	3050	1450
1–8	Bobcaygeon	18	120	57
8–15	Bobcaygeon	18	10	5
			3200	1510
			7500	3550
Dalton Township Municipality				
1–8	Shadow Lake	18	50	24
0–1	Shadow Lake & Gull River	18	146	70
1–8	Shadow Lake & Gull River	18	147	70
			295	140
0–1	Gull River	18	375	179
1–8	Gull River	18	34	16
			410	195
0–1	Bobcaygeon	18	67	32
			820	390
TOTAL FOR REPORT AREA:			9600	4500

TABLE 5. QUARRIES, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

1 NO.	2 FACE HEIGHT Metres	3 REMARKS
Longford Geographic Township		
		– none –
Digby Geographic Township		
		– none –
Laxton Geographic Township		
1	<0.9	thin– to medium–bedded Gull River Formation limestone, active flagstone quarry
2	<0.9	flagstone quarry
3	<0.9	thin– to medium–bedded Gull River Formation limestone, abandoned flagstone quarry
4	<0.3	thin–bedded Gull River Formation limestone, flagstone quarry, active on demand
5	3.0–3.7	medium–bedded Gull River Formation limestone, abandoned
6	4.6–6.0	Precambrian gneiss
Dalton Township Municipality		
		– none –

TABLE 6. SELECTED BEDROCK RESOURCE AREAS, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

1 DEPOSIT NO.	2 DEPTH OF OVERBURDEN Metres	3 AREA Hectares	4 CULTURAL SETBACKS Hectares	5 EXTRACTED AREA Hectares	6 AVAILABLE AREA Hectares	7 ESTIMATED WORKABLE THICKNESS Metres	8 AVAILABLE RESOURCES Millions of Tonnes
Longford Geographic Township							
				– none –			
Digby Geographic Township							
1	0–1	375	131	0	244	18	116
	1–8	680	102	0	580	18	275
		1060	233	0	820		390
2	0–1	7	3	0	4	18	2
		1070	236	0	820		395
Laxton Geographic Township							
1	0–1	3300	415	5	2900	18	1380
	1–8	950	300	0	650	18	310
		4250	720	5	3550		1690
2	0–1	3050	280	0	2770	18	1320
	1–8	120	10	0	110	18	52
		3150	290	0	2900		1370
		7400	1010	5	6400		3060
Dalton Township Municipality							
1	0–1	275	5	0	270	18	129
	1–8	21	9	0	12	18	6
		295	14	0	280		135
2	0–1	67	0	0	67	18	32
		360	14	0	345		167
TOTAL FOR REPORT AREA:		8800	1260	5	7600		3600

TABLE 7. SUMMARY OF TEST HOLE DATA, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

– NONE –

TABLE 8. SUMMARY OF GEOPHYSICS DATA, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

– NONE –

TABLE 9. RESULTS OF AGGREGATE QUALITY TESTS, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

	COARSE AGGREGATE					FINE AGGREGATE
	Petrographic Number					
Sample No.	Granular & 16 mm Crushed	Hot Mix & Concrete	Magnesium Sulphate Soundness (% Loss)	Absorption (%)	Los Angeles Abrasion (% Loss)	Magnesium Sulphate Soundness (% Loss)
Pit 4	124	193	10	0.90	–	24
Pit 15	122	167	12	0.80	–	20
Pit 20	142	186	11	0.92	–	23
Pit 36	120	152	7	0.60	–	16
Pit 42	123	156	6	0.63	–	16

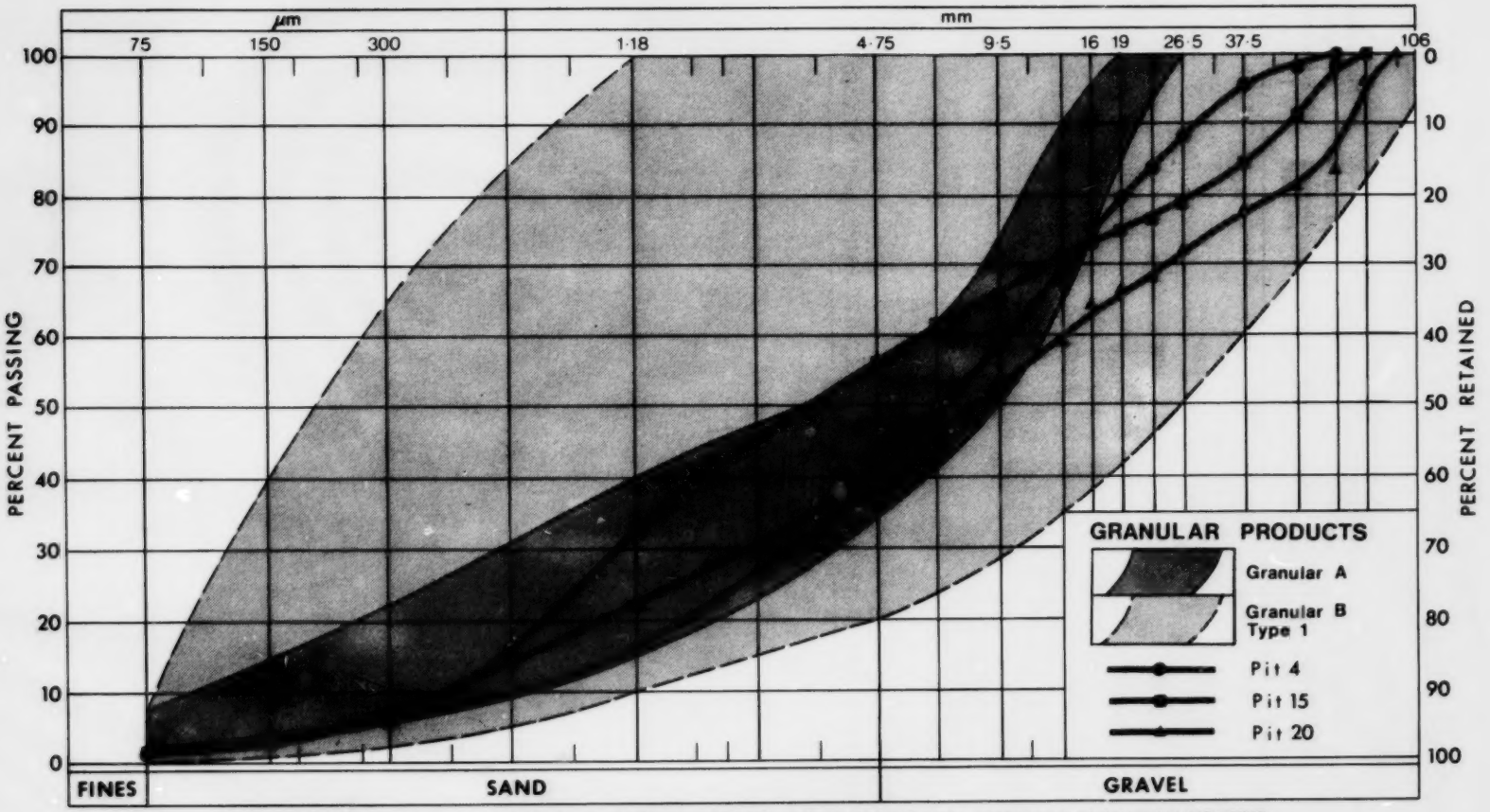


FIGURE 3a. AGGREGATE GRADING CURVES, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from Ontario Provincial Standard Specifications OPSS 1010, 1988).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

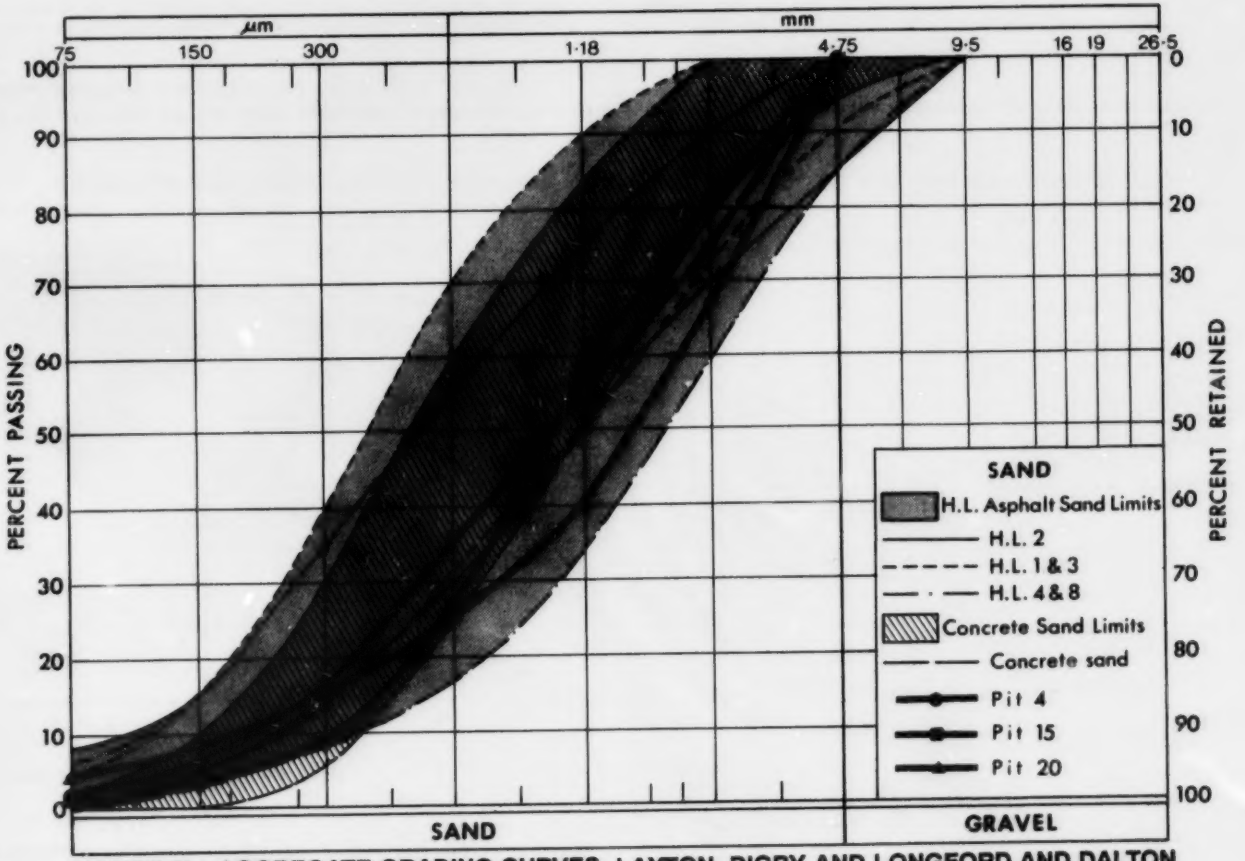


FIGURE 3b. AGGREGATE GRADING CURVES, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from Ontario Provincial Standards Specifications OPSS 1002, 1988 and 1003, 1988)

NOTE:

Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

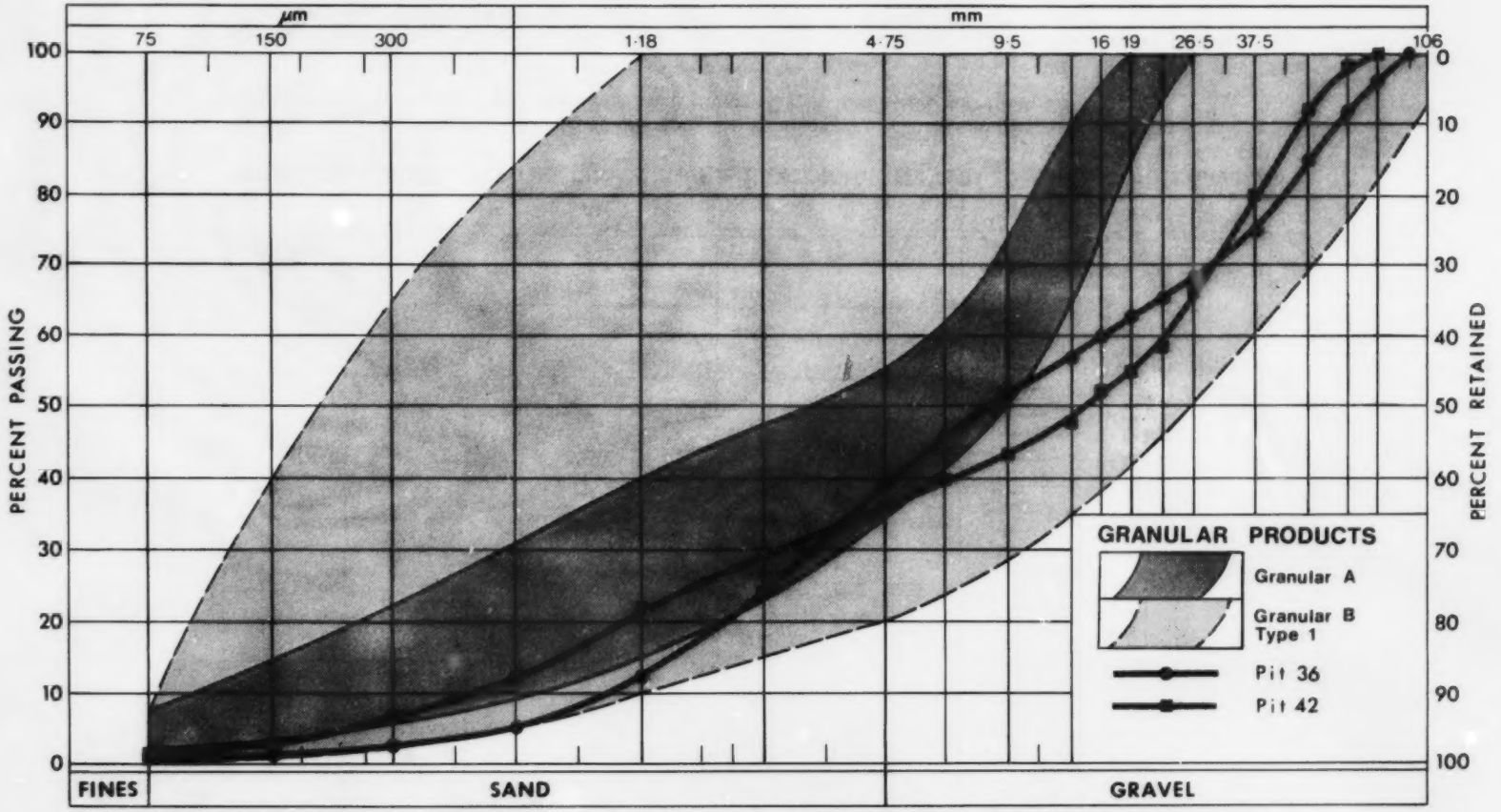


FIGURE 4a. AGGREGATE GRADING CURVES, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from Ontario Provincial Standard Specifications OPSS 1010, 1988).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

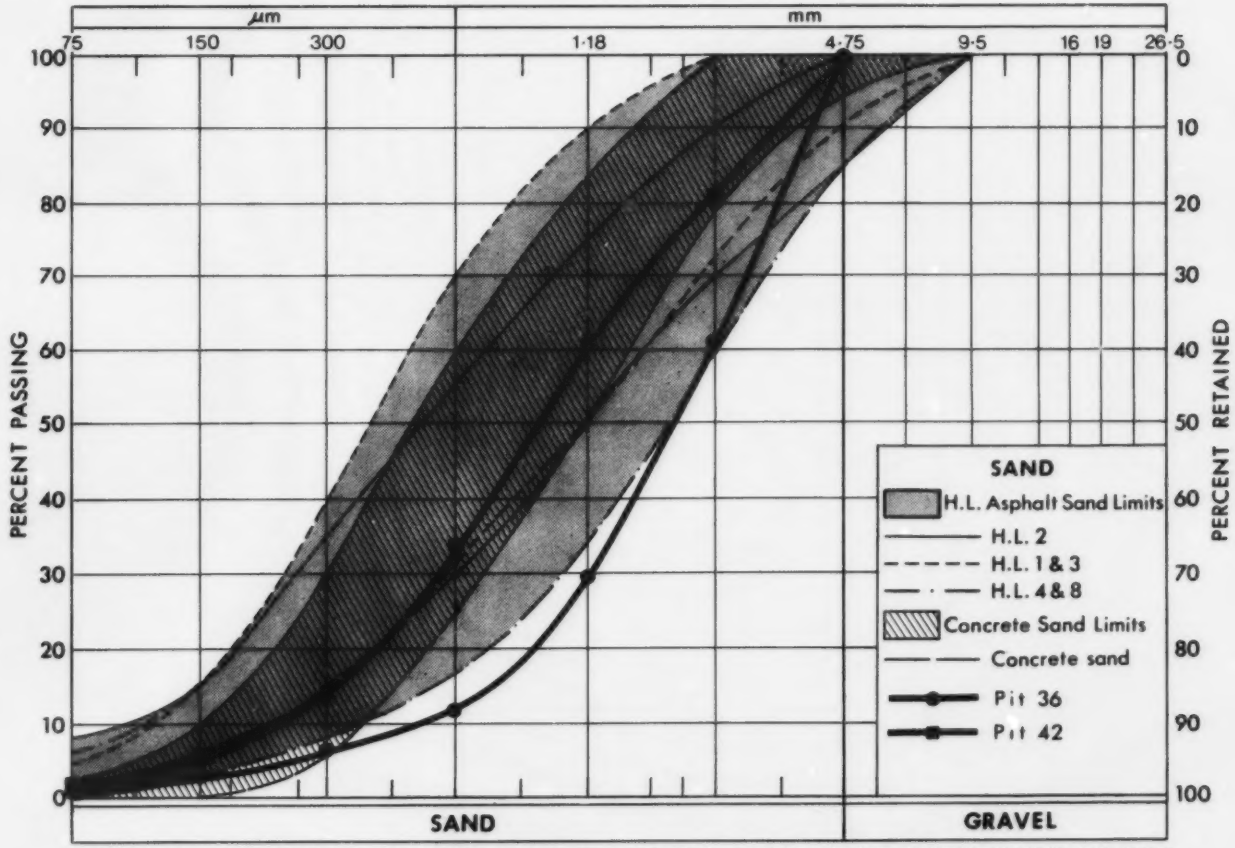


FIGURE 4b. AGGREGATE GRADING CURVES, LAXTON, DIGBY AND LONGFORD AND DALTON TOWNSHIPS.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from Ontario Provincial Standards Specifications OPSS 1002, 1988 and 1003, 1988)

NOTE:

Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

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Appendix B — Glossary

Abrasion Resistance: Tests such as the Los Angeles abrasion test are used to measure the ability of aggregate to resist crushing and pulverizing under conditions similar to those encountered in processing and use. Measuring resistance is an important component in the evaluation of the quality and prospective uses of aggregate. Hard, durable material is preferred for road building.

Absorption Capacity: Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate.

Aggregate: Any hard, inert, construction material (sand, gravel, shells, slag, crushed stone or other mineral material) used for mixing in various-sized fragments with a cement or bituminous material to form concrete, mortar, etc., or used alone for road building or other construction. Synonyms include mineral aggregate and granular material.

Aggregate Abrasion Value: This test directly measures the resistance of aggregate to abrasion with silica sand and a steel disk. The higher the value, the lower the resistance to abrasion. For high quality asphalt surface course uses, values of less than 6 are desirable.

Alkali-aggregate Reaction: A chemical reaction between the alkalies of Portland cement and certain minerals found in rocks used for aggregate. Alkali-aggregate reactions are undesirable because they can cause expansion and cracking of concrete. Although perfectly suitable for building stone and asphalt applications, alkali- reactive aggregates should be avoided for structural concrete uses.

Beneficiation: Beneficiation of aggregates is a process or combination of processes which improves the quality (physical properties) of a mineral aggregate and is not part of the normal processing for a particular use, such as routine crushing, screening, washing or classification. Heavy media separation, jigging or application of special crushers (e.g., "cage mill") are usually considered processes of beneficiation.

Blending: Required in cases of extreme coarseness, fineness or other irregularities in the gradation of unprocessed aggregate. Blending is done with approved sand-sized aggregate in order to satisfy the gradation requirements of the material.

Bulk Relative Density: An aggregate with low relative density is lighter in weight than one with a high relative density. Low relative density aggregates (less than about 2.5) are often nondurable for many aggregate uses.

Cambrian: The first period of the Paleozoic Era, thought to have covered the time between 570 and 500 million years ago. The Cambrian precedes the Ordovician Period.

Clast: An individual constituent, grain or fragment of a sediment or rock, produced by the mechanical weathering of a larger rock mass. Synonyms include particle and fragment.

Crushable Aggregate: Unprocessed gravel containing a minimum of 35% coarse aggregate larger than the No. 4 sieve (4.75 mm) as well as a minimum of 20% greater than the 26.5 mm sieve.

Deleterious Lithology: A general term used to designate those rock types which are chemically or physically unsuited for use as construction or road-building aggregates. Such lithologies as chert, shale, siltstone and sandstone may deteriorate rapidly when exposed to traffic and other environmental conditions.

Devonian: A period of the Paleozoic Era thought to have covered the span of time between 395 and 345 million years ago, following the Silurian Period. Rocks formed in the Devonian Period are among the youngest found in Ontario.

Dolostone: A carbonate sedimentary rock consisting chiefly of the mineral dolomite and containing relatively little calcite (dolostone is also known as dolomite).

Drift: A general term for all unconsolidated rock debris transported from one place and deposited in another, distinguished from underlying bedrock. In North America, glacial activity has been the dominant mode of transport and deposition of drift. Synonyms include overburden and surficial deposit.

Drumlin: A low, smoothly rounded, elongated hill, mound or ridge composed of glacial materials. These landforms were formed beneath an advancing ice sheet, and were shaped by its flow.

Eolian: Pertaining to the wind, especially with respect to landforms whose constituents were transported and deposited by wind activity. Sand dunes are an example of an eolian landform.

Fines: A general term used to describe the size fraction of an aggregate which passes (is finer than) the No. 200 mesh screen (0.075 mm). Also described informally as "dirt", these particles are in the silt and clay size range.

Glacial lobe: A tongue-like projection from the margin of the main mass of an ice cap or ice sheet. During the Pleistocene Epoch several lobes of the Laurentide continental ice sheet occupied the Great Lakes basins. These lobes advanced then melted back numerous times during the Pleistocene, producing the complex arrangement of glacial landforms found in Ontario.

Gneiss: A coarse-textured metamorphic rock with the minerals arranged in parallel streaks or bands. Gneiss is relatively rich in feldspar. Other common minerals found in this rock include quartz, mica, amphibole and garnet.

Gradation: The proportion of material of each particle size, or the frequency distribution of the various sizes which constitute a sediment. The strength, durability, permeability and stability of an aggregate depend to a great extent on its gradation. The size limits for different particles are as follows:

Boulder	more than 200 mm
Cobbles	75-200 mm
Coarse Gravel	26.5-75 mm
Fine Gravel	4.75-26.5 mm
Coarse Sand	2-4.75 mm
Medium Sand	0.425-2 mm
Fine Sand	0.075-0.425 mm
Silt, Clay	less than 0.075 mm

Granite: A coarse-grained, light-coloured rock that ordinarily has an even texture and is composed of quartz and feldspar with either mica, hornblende or both.

Granular Base and Subbase: Components of a pavement structure of a road, which are placed on the subgrade and are designed to provide strength, stability and drainage, as well as, support for surfacing materials. Four types have been defined: Granular A consists of crushed and processed aggregate and has relatively stringent quality standards in comparison to Granular B which is usually pit-run or other unprocessed aggregate, Granular M is a shouldering and surface dressing material with quality requirements similar to Granular A, and Select Subgrade Material has similar quality requirements to Granular B and it provides a stable platform for the overlying pavement structure. (For more specific information the reader is referred to Ontario Provincial Standard Specification OPSS 1010).

Hot-laid (or Asphaltic) Aggregate: Bituminous, cemented aggregates used in the construction of pavements either as surface or bearing course (HL 1, 3 and 4), or as binder course (HL 2 and 8) used to bind the surface course to the underlying granular base.

Lithology: The description of rocks on the basis of such characteristics as colour, structure, mineralogic composition and grain size. Generally, the description of the physical character of a rock.

Los Angeles Abrasion and Impact Test: This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium Sulphate Soundness Test: This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates which are susceptible to freezing and thawing will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Meltwater Channel: A drainage way, often terraced, produced by water flowing away from a melting glacier margin.

Ordovician: An early period of the Paleozoic Era thought to have covered the span of time between 500 and 435 million years ago.

Paleozoic Era: One of the major divisions of the geologic time scale thought to have covered the time between 570 and 230 million years ago, the Paleozoic Era (or Ancient Life Era) is subdivided into six geologic periods, of which only four (Cambrian, Ordovician, Silurian and Devonian) can be recognized in southern Ontario.

Petrographic Examination: An aggregate quality test based on known field performance of various rock types. In Ontario the test result is a Petrographic Number (PN). The higher the PN, the lower the quality of the aggregate.

Pleistocene: An epoch of the recent geological past including the time from approximately 2 million years ago to 7000 years ago. Much of the Pleistocene was characterized by extensive glacial activity and is popularly referred to as the "Great Ice Age".

Polished Stone Value: This test measures the frictional properties of aggregates after 6 hours of abrasion and polishing with an emery abrasive. The higher the PSV, the higher the frictional properties of the aggregate. Values less than 45 indicate marginal frictional properties, while values greater than 55 indicate excellent frictional properties.

Possible Resource: Reserve estimates based largely on broad knowledge of the geological character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on assumed continuity or repetition for which there are reasonable geological indications.

Precambrian: The earliest geological period extending from the consolidation of the earth's crust to the beginning of the Cambrian.

Shale: A fine-grained, sedimentary rock formed by the consolidation of clay, silt or mud and characterized by well developed bedding planes, along which the rock breaks readily into thin layers. The term shale is also commonly used for fissile claystone, siltstone and mudstone.

Silurian: An early period of the Palezoic Era thought to have covered the time between 435 and 395 million years ago. The Silurian follows the Ordovician Period and precedes the Devonian Period.

Soundness: The ability of the components of an aggregate to withstand the effects of various weathering processes and agents. Unsound lithologies are subject to disintegration caused by the expansion of absorbed solutions. This may seriously impair the performance of road-building and construction aggregates.

Till: Unsorted and unstratified rock debris, deposited directly by glaciers and ranging in size from clay to large boulders.

Wisconsinan: Pertaining to the last glacial period of the Pleistocene Epoch in North America. The Wisconsinan began approximately 100 000 years ago and ended approximately 7000 years ago. The glacial deposits and landforms of southern Ontario are predominantly the result of glacial activity during the Wisconsinan Stage.

Appendix C — Geology of Sand and Gravel Deposits

The type, distribution and extent of sand and gravel deposits in southern Ontario are the result of extensive glacial and glacially influenced activity in Wisconsinan time during the Pleistocene Epoch, approximately 100 000 to 7000 years ago. The deposit types reflect the different depositional environments that existed during the melting and retreat of the continental ice masses, and can readily be differentiated on the basis of their morphology, structure and texture. The deposit types are described below.

GLACIOFLUVIAL DEPOSITS

These deposits can be divided into two broad categories: those that were formed in contact with (or in close proximity to) glacial ice, and those that were deposited by meltwaters carrying materials beyond the ice margin.

Ice-Contact Terraces (ICT): These are glaciofluvial features deposited between the glacial margin and a confining topographic high, such as the side of a valley. The structure of the deposits may be similar to that of outwash deposits, but in most cases the sorting and grading of the material is more variable and the bedding is discontinuous because of extensive slumping. The probability of locating large amounts of crushable aggregate is moderate, and extraction may be expensive because of the variability of the deposits both in terms of quality and grain size distribution.

Kames (K): Kames are defined as mounds of poorly sorted sand and gravel deposited by meltwater in depressions or fissures on the ice surface or at its margin. During glacial retreat, the melting of supporting ice causes collapse of the deposits, producing internal structures characterized by bedding discontinuities. The deposits consist mainly of irregularly bedded and crossbedded, poorly sorted sand and gravel. The present forms of the deposits include single mounds, linear ridges (crevasse fillings) or complex groups of landforms. The latter are occasionally described as "undifferentiated ice-contact stratified drift" (IC) when detailed subsurface information is unavailable. Since kames commonly contain large amounts of fine-grained material and are characterized by considerable variability, there is generally a low to moderate probability of discovering large amounts of good quality, crushable aggregate. Extractive problems encountered in these deposits are mainly the excessive variability of the aggregate and the rare presence of excess fines (silt- and clay-sized particles).

Eskers (E): Eskers are narrow, sinuous ridges of sand and gravel deposited by meltwaters flowing in tunnels within or at the base of glaciers, or in channels on the ice surface. Eskers vary greatly in size. Many, though not all eskers, consist of a central core of poorly sorted and stratified gravel characterized by a wide range in grain size. The core material is often draped on its flanks by better sorted and stratified gravel. The deposits have a high probability of containing a large proportion of crushable aggregate, and since they are generally built above the surrounding ground surface, are convenient extraction sites. For these reasons esker deposits have been traditional aggregate sources throughout Ontario, and are significant components of the total resources of many areas.

Some planning constraints and opportunities are inherent in the nature of the deposits. Because of their linear nature, the deposits commonly extend across several property boundaries leading to unorganized extractive development at numerous small pits. On the other hand, because of their form, eskers can be easily and inexpensively extracted and are amenable to rehabilitation and sequential land use.

Undifferentiated Ice-Contact Stratified Drift (IC): This designation may include deposits from several ice-contact, depositional environments which usually form extensive, complex landforms. It is not feasible to identify individual areas of coarse-grained material within such deposits because of their lack of continuity and grain size variability. They are given a qualitative rating based on existing pit and other subsurface data.

Outwash (OW): Outwash deposits consist of sand and gravel laid down by meltwaters beyond the margin of the ice lobes. The deposits occur as sheets or as terraced valley fills (valley trains) and may be very large in extent and thickness. Well developed outwash deposits have good horizontal bedding and are uniform in grain size distribution. Outwash deposited near the glacier's margin is much more variable in texture and structure. The probability of locating useful crushable aggregates in outwash deposits is moderate to high depending on how much information on size, distribution and thickness is available.

Subaqueous Fan (SF): Subaqueous fans are formed within or near the mouths of meltwater conduits when sediment laden meltwaters are discharged into a standing body of water. The geometry of the resulting deposit is fan or lobe shaped. Several of these lobes may be joined together to form a larger, continuous sedimentary body. Internally, subaqueous fans consist of stratified sands and gravels which may exhibit wide variations in grain size distribution. As these features were deposited under glacial lake waters, silt and clay which settled out of these lakes may be associated in varying amounts with these deposits. The variability of the sediments and presence of fines are the main extractive problems associated with these deposits.

Alluvium (AL): Alluvium is a general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during postglacial time by a stream as sorted or semi-sorted sediment, on its bed or on its floodplain.

The probability of locating large amounts of crushable aggregate in alluvial deposits is low, and they have generally low value because of the presence of excess silt- and clay-sized material. There are few large post-glacial alluvium deposits in Ontario.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine Beach Deposits (LB): These are relatively narrow, linear features formed by wave action at the shores of glacial lakes that existed at various times during the deglaciation of southern Ontario. Well developed lacustrine beaches are usually less than 6 m thick. The aggregate is well sorted and stratified and sand-sized material commonly predominates. The composition and size distribution of the deposit depends on the nature of the source material. The probability of obtaining crushable aggregate is high when the material is developed from coarse-grained materials such as a stony till, and low when developed from fine-grained materials. Beaches are relatively narrow, linear deposits, so that extractive operations are often numerous and extensive.

Glaciolacustrine Deltas (LD): These features were formed where streams or rivers of glacial meltwater flowed into lakes and deposited their suspended sediment. In southern Ontario, such deposits tend to consist mainly of sand and abundant silt. However, in near-ice and ice-contact positions, coarse material may be present. Although deltaic deposits may be large, the probability of obtaining coarse material is generally low.

Glaciolacustrine Plains (LP): The nearly level surface marking the floor of an extinct glacial lake. The sediments which form the plain are predominantly fine to medium sand, silt and clay, and were deposited in relatively deep water. Lacustrine deposits are generally of low value as aggregate sources because of their fine grain size and lack of crushable material. In some aggregate-poor areas, lacustrine deposits may constitute valuable sources of fill and some granular subbase aggregate.

GLACIAL DEPOSITS

Moraines (M): These are belts of glacial drift deposited at, and parallel to, glacier margins. End moraines commonly consist of ice-contact stratified drift and in such instances are usually called kame moraines. Kame moraines commonly result from deposition between two glacial lobes (interlobate moraines). The probability of locating aggregates within such features is moderate to low. Exploration and development costs are high. Moraines may be very large and contain vast aggregate resources, but the location of the best areas within the moraine is usually poorly defined.

EOLIAN DEPOSITS

Windblown Deposits (WD): Windblown deposits are those formed by the transport and deposition of sand by winds. The form of the deposits ranges from extensive, thin layers to well developed linear and crescentic ridges known as dunes. Most windblown deposits in southern Ontario are derived from, and deposited on, pre-existing lacustrine sand plain deposits. Windblown sediments almost always consist of fine to coarse sand and are usually well sorted. The probability of locating crushable aggregate in windblown deposits is very low.

Appendix D — Geology of Bedrock Deposits

The purpose of this appendix is to familiarize the reader with the general bedrock geology of southern Ontario (Figure D1), and the potential uses of the various bedrock formations where known. The reader is cautioned against using this information for more specific purposes. The stratigraphic chart (Figure D2) is intended only to illustrate the stratigraphic sequences in particular geographic areas and should not be used as a regional correlation table.

The following description is arranged in ascending stratigraphic order, on a group and formation basis. Precambrian rocks are not discussed. Additional stratigraphic information is included for some formations where necessary. The publications and maps of the Ontario Geological Survey and the Geological Survey of Canada should be referred to for more detailed information. The composition, thickness and uses of the formations are discussed. If a formation may be suitable for use as aggregate and aggregate suitability test data is available, the data has been included in the form of ranges. The following short forms have been used in presenting this data: PSV = Polished Stone Value, AAV = Aggregate Abrasion Value, $MgSO_4$ = Magnesium Sulphate Soundness Test (loss in percent), LA = Los Angeles Abrasion and Impact Test (loss in percent), Absn = Absorption (percent), BRD = Bulk Relative Density, PN (Asphalt & Concrete) = Petrographic Number for Asphalt and Concrete use.

The ranges are intended as a guide only and care should be exercised in extrapolating the information to specific situations. Aggregate suitability test data has been provided by the Ontario Ministry of Transportation.

Covey Hill Formation (Cambrian)

STRATIGRAPHY: lower formation of the Potsdam Group. COMPOSITION: interbedded noncalcareous feldspathic conglomerate and sandstone. THICKNESS: 0 to 14 m. USES: has been quarried for aggregate in South Burgess Township, Leeds County.

Nepean Formation (Cambro-Ordovician)

STRATIGRAPHY: upper formation of the Potsdam Group. COMPOSITION: thin-bedded to massive quartz sandstone with some conglomerate interbeds and rare shaly partings. THICKNESS: 0 to 30 m. USES: suitable as dimension stone; quarried at Philipsville and Forfar for silica sand; alkali-silica reactive in Portland cement concrete. AGGREGATE SUITABILITY TESTING: PSV = 54-68, AAV = 4-15, $MgSO_4$ = 9-32, LA = 44-90, Absn = 1.6-2.6, BRD = 2.38-2.50, PN (Asphalt & Concrete) = 130-140.

March Formation (Lower Ordovician)

STRATIGRAPHY: lower formation of the Beekmantown Group. COMPOSITION: interbedded quartz sandstone, dolomitic quartz sandstone, sandy dolostone and dolostone. THICKNESS: 18 to 60 m. USES: quarried extensively for aggregate in areas of subcrop and outcrop; alkali-silica reactive in Portland cement concrete; lower part of formation is an excellent source of skid-resistant aggregate; suitable for use as facing stone and paving stone. AGGREGATE SUITABILITY TESTING: PSV = 55-60, AAV = 4-6, $MgSO_4$ = 1-17, LA = 15-38, Absn = 0.5-0.9, BRD = 2.61-2.65, PN (Asphalt & Concrete) = 110-150.

Oxford Formation (Lower Ordovician)

STRATIGRAPHY: upper formation of the Beekmantown Group. COMPOSITION: thin- to thick-bedded, microcrystalline to medium-crystalline, grey dolostone with thin shaly interbeds. THICKNESS: 61 to 102 m. USES: quarried in the Brockville and Smith Falls areas and south of Ottawa for use as aggregate. AGGREGATE SUITABILITY TESTING: PSV = 47-48, AAV = 7-8, $MgSO_4$ = 1-4, LA = 18-23, Absn = 0.7-0.9, BRD = 2.74-2.78, PN (Asphalt & Concrete) = 105-120.

Rockcliffe Formation (Middle Ordovician)

STRATIGRAPHY: divided into lower member and upper (St. Martin) member. COMPOSITION: interbedded quartz sandstone and shale; interbedded shaly bioclastic limestone and shale predominating in upper member to the east. THICKNESS: 0 to 125 m. USES: upper member has been quarried east of Ottawa for aggregate; lower member has been used as crushed stone; some high purity limestone beds in upper member may be suitable for use as fluxing stone and in lime production. AGGREGATE SUITABILITY TESTING: PSV = 58-63, AAV = 10-11, $MgSO_4$ = 12-40, LA = 25-28, Absn = 1.8-1.9, BRD = 2.55-2.62, PN (Asphalt & Concrete) = 122-440.

Shadow Lake Formation (Middle Ordovician)

STRATIGRAPHY: in eastern Ontario, the basal unit of the Ottawa Group; in central Ontario, overlain by the Simcoe Group. COMPOSITION: in eastern Ontario, silty and sandy dolostone with shale partings and minor interbeds of sandstone; in central Ontario,

conglomerates, sandstones and shales. THICKNESS: in eastern Ontario, 2 to 3 m; in central Ontario, 0 to 12 m. USES: potential source of decorative stone; very limited value as aggregate source.

Gull River Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and Ottawa Group (eastern Ontario). In central and eastern Ontario, the formation is subdivided into upper and lower members; west of Lake Simcoe, it is presently subdivided into upper, middle and lower members. COMPOSITION: in central and eastern Ontario, the lower member consists of alternating units of limestone, dolomitic limestone and dolostone, the upper member consists of thin-bedded limestones with thin shale partings; west of Lake Simcoe, the lower member is thin- to thick-bedded, interbedded, grey argillaceous limestone and buff to green dolostone, whereas the upper and middle members are dense microcrystalline limestones with argillaceous dolostone interbeds. THICKNESS: 7 to 62 m. USES: quarried in the Lake Simcoe, Kingston, Ottawa and Cornwall areas for crushed stone; rock from certain layers in eastern and central Ontario has proven to be alkali-reactive when used in Portland cement concrete (alkali-carbonate reaction). AGGREGATE SUITABILITY TESTING: PSV = 41-49, AAV = 8-12, $MgSO_4$ = 3-13, LA = 18-28, Absn = 0.3-0.9, BRD = 2.68-2.73, PN (Asphalt & Concrete) = 100-153.

Bobcaygeon Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and the Ottawa Group (eastern Ontario), subdivided into upper, middle and lower members; members in eastern and central Ontario are approximately equivalent. COMPOSITION: homogeneous, massive to thin-bedded fine-crystalline limestone with numerous shaly partings in the middle member. THICKNESS: 24 to 87 m. USES: quarried at Brechin, Marysville and in the Ottawa area for crushed stone; generally suitable for use as granular base aggregate; rock from certain layers has been found to be alkali-reactive when used in Portland cement concrete (alkali-silica reaction). AGGREGATE SUITABILITY TESTING: PSV = 47-51, AAV = 14-23, $MgSO_4$ = 1-40, LA = 18-32, Absn = 0.3-2.4, BRD = 2.5-2.69, PN (Asphalt & Concrete) = 100-320.

Verulam Formation (Middle Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa groups. COMPOSITION: fossiliferous, pure to argillaceous limestone interbedded with calcareous shale. THICKNESS: 32 to 70 m. USES: quarried at Picton and Bath for use in cement manufacture; quarried for aggregate in Mara Township, Simcoe County and in the Belleville-Kingston area; may be unsuitable for use as aggregate in some areas because of its high shale content. AGGREGATE SUITABILITY TESTING: PSV = 43-44, AAV = 9-13, $MgSO_4$ = 4-45, LA = 22-29, Absn = 0.4-2.1, BRD = 2.59-2.70, PN (Asphalt & Concrete) = 120-255.

Lindsay Formation (Middle and Upper Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa groups; in eastern Ontario, it is divisible into an unnamed lower member and the Eastview Member; in central Ontario, it is divisible into the Collingwood Member (equivalent to portions of the Eastview Member) and a lower member. COMPOSITION: in eastern Ontario, the lower member is interbedded, very fine- to coarse-crystalline limestone with undulating shale partings and interbeds of dark grey calcareous shale, whereas the Eastview Member is an interbedded dark grey to dark brown calcareous shale and very fine- to fine-crystalline, petroliferous limestone; in central Ontario, Collingwood Member is a black, calcareous shale whereas the lower member is a very fine- to coarse-crystalline, thin-bedded limestone with very thin, undulating shale partings. THICKNESS: 25 to 61 m. USES: in eastern Ontario, the lower member is used extensively for aggregate production; in central Ontario, it is quarried at Picton, Ogden Point and Bowmanville for cement; may be suitable or unsuitable for use as concrete and asphalt aggregate. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 2-47, LA = 20-28, Absn = 0.4-1.3, BRD = 2.64-2.70, PN (Asphalt & Concrete) = 110-215.

Blue Mountain and Billings Formations (Upper Ordovician)

STRATIGRAPHY: in central Ontario, Blue Mountain Formation includes the upper and middle members of the former Whitby Formation; in eastern Ontario, Billings Formation is equivalent to part of the Blue Mountain Formation. COMPOSITION: the Blue Mountain Formation is blue-grey, noncalcareous shale; Billings Formation is dark grey to black, noncalcareous to slightly calcareous, pyritiferous shale with dark grey limestone laminae and grey siltstone interbeds. THICKNESS: Blue Mountain Formation - 43 to 61 m; Billings Formation - 0 to 62 m. USES: Billings Formation may be a suitable source for structural clay products and expanded aggregate; Blue Mountain Formation may be suitable for structural clay products.

Georgian Bay and Carlsbad Formations (Upper Ordovician)

COMPOSITION: in central Ontario, the Georgian Bay Formation is composed of interbedded limestone and shale; in eastern Ontario, the Carlsbad Formation is composed of interbedded shale, siltstone and bioclastic limestone; THICKNESS: Georgian Bay Formation – 91 to 170 m; Carlsbad Formation - 0 to 186 m. USES: Georgian Bay Formation is used by several pro-

ducers in Metropolitan Toronto area to produce brick and structural tile, as well as for making Portland cement; at Streetsville, expanded shale was used in the past to produce lightweight aggregate; Carlsbad Formation is used as a source material for brick and tile manufacturing, has potential as a lightweight expanded aggregate.

Queenston Formation (Upper Ordovician)

COMPOSITION: red, thin- to thick-bedded, sandy to argillaceous shale with green mottling and banding. THICKNESS: 122 to 152 m. USES: there are several large quarries developed in the Queenston Formation in the Toronto-Hamilton region and one at Russell, near Ottawa; all extract shale for brick manufacturing; the Queenston Formation is the most important source material for brick manufacture in Ontario.

Whirlpool Formation (Lower Silurian)

STRATIGRAPHY: lower formation in the Cataract Group in the Niagara Peninsula and the Niagara Escarpment as far north as Duntroon. COMPOSITION: massive, medium- to coarse-grained, argillaceous white to light grey quartz sandstone with thin grey shale partings. THICKNESS: 0 to 8 m. USES: building stone, flagstone.

Manitoulin Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs north of Stoney Creek. COMPOSITION: thin-bedded, blue-grey to buff brown dolomitic limestones and dolostones. THICKNESS: 0 to 23 m. USES: extracted for crushed stone in St. Vincent Township, Grey County and for decorative stone on Manitoulin Island. AGGREGATE SUITABILITY TESTING: no data.

Cabot Head Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs throughout southern Ontario, south and north of the Niagara Escarpment. COMPOSITION: green, grey and red shales. THICKNESS: 15 to 18 m; USES: potential source of coated lightweight aggregate and raw material for use in manufacture of brick and tile; lack of suitable exposures has limited its use.

Grimsby Formation

STRATIGRAPHY: upper formation of the Cataract Group, is identified on the Niagara Peninsula as far north as Clappison's Corners. COMPOSITION: interbedded sandstone and shale, mostly red. THICKNESS: 0 to 15 m. USES: no present uses.

Thorold Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on the Niagara Peninsula. COMPOSITION: thick-bedded quartz sandstone. THICKNESS: 2 to 3 m. USES: no present uses.

Neagha Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on the Niagara Peninsula. COMPOSITION: dark grey to green shale with minor interbedded limestone. THICKNESS: 0 to 2 m. USES: no present uses.

Dyer Bay Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: highly fossiliferous, impure dolostone. THICKNESS: 0 to 6 m. USES: no present uses.

Wingfield Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: olive green to grey shale with dolostone interbeds. THICKNESS: 0 to 11 m. USES: no present uses.

St. Edmund Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula, upper portion previously termed the Mindemoya Formation. COMPOSITION: pale grey to buff brown, micro- to medium-crystalline, thin- to medium-bedded dolostone. THICKNESS: 0 to 26 m. USES: quarried for fill and crushed stone on Manitoulin Island. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-2, LA = 19-21, Absn = 0.6-0.7, BRD = 2.78-2.79, PN (Asphalt & Concrete) = 105.

Fossil Hill and Reynales Formations (Middle Silurian)

STRATIGRAPHY: part of Clinton Group; Fossil Hill Formation occurs in the northern part of the Niagara Escarpment and is approximately equivalent in part, to the Reynales Formation which occurs on the Niagara Peninsula and the Escarpment, as far north as the Forks of the Credit. COMPOSITION: Fossil Hill Formation is fine- to coarse-crystalline dolostone with high silica content; Reynales Formation is thin- to thick-bedded shaly dolostone and dolomitic limestone. THICKNESS: Fossil Hill Formation - 6 to 26 m; Reynales Formation - 0 to 3 m. USES: both formations quarried for aggregate with overlying Amabel and Lockport formations. AGGREGATE SUITABILITY TESTING: (Fossil Hill Formation on Manitoulin Island) $MgSO_4$ = 41, LA = 29, Absn = 4.1, BRD = 2.45, PN (Asphalt & Concrete) = 370.

Irondequoit Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group on the Niagara Peninsula south of Waterdown. COMPOSITION: massive, coarse-crystalline crinoidal limestone. THICKNESS: 0 to 2 m. USES: not significantly utilized.

Rochester Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group along the Niagara Peninsula. COMPOSITION: black to dark grey calcareous shale with numerous limestone lenses. THICKNESS: 5 to 18 m. USES: not significantly utilized. AGGREGATE SUITABILITY TESTING: PSV = 69, AAV = 17, $MgSO_4$ = 95, LA = 19, Absn = 2.2, BRD = 2.67, PN (Asphalt & Concrete) = 400.

Decew Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group south of Waterdown along the Niagara Peninsula. COMPOSITION: sandy to shaly dolomitic limestone and dolostone. THICKNESS: 0 to 5 m. USES: too shaly for high quality uses, but is quarried along with Lockport Formation in places. AGGREGATE SUITABILITY TESTING: PSV = 67, AAV = 15, $MgSO_4$ = 55, LA = 21, Absn = 2.2, BRD = 2.66, PN (Asphalt & Concrete) = 255.

Lockport and Amabel Formations (Middle Silurian)

STRATIGRAPHY: Lockport Formation occurs from Waterdown to Niagara Falls, subdivided into 3 formal members: Gasport, Goat Island and Eramosa members and an informal member (the "Vinemount shale beds"); the stratigraphically equivalent Amabel Formation, found from Waterdown to Cockburn Island, is subdivided into Lions Head, Wiarton/Colpoy Bay and Eramosa members. COMPOSITION: Lockport Formation is thin- to massive-bedded, fine- to medium-crystalline dolostone; Amabel Formation is thin-bedded to massive, medium-crystalline dolostone with reef facies near Georgetown and on the Bruce Peninsula. THICKNESS: (Lockport/ Amabel) 3 to 40 m. USES: both formations have been used to produce lime, crushed stone, concrete aggregate and building stone throughout their area of occurrence, and are a resource of provincial significance. AGGREGATE SUITABILITY TESTING: PSV = 36-49, AAV = 10-17, $MgSO_4$ = 2-6, LA = 25-32, Absn = 0.4-1.54, BRD = 2.61-2.81, PN (Asphalt & Concrete) = 100-105.

Guelph Formation (Middle Silurian)

STRATIGRAPHY: exposed on the Niagara Escarpment from the Niagara River to the tip of the Bruce Peninsula, mostly present in the subsurface of southwestern Ontario. COMPOSITION: micro-crystalline to medium-crystalline, thick-bedded, soft, porous dolostone, characterized in places by extensive vuggy, porous reefal facies of high chemical purity. THICKNESS: 30 to 52 m. USES: some areas appear soft and unsuitable for use in the production of load-bearing aggregate; this unit requires additional testing to fully establish its aggregate suitability; main use is for dolomitic lime for cement manufacture; quarried near Hamilton and Guelph.

Salina Formation (Upper Silurian)

STRATIGRAPHY: present in the subsurface of southwestern Ontario; rarely exposed at the surface. COMPOSITION: grey and maroon shale, brown dolostone and, in places, salt, anhydrite and gypsum; consists predominantly of evaporitic rich material with up to eight units identifiable. THICKNESS: 113 to 183 m. USES: gypsum mines at Hagersville, Caledonia and Drumbo; salt is mined at Goderich and Windsor and is produced from brine wells at Amherstburg, Windsor and Sarnia.

Bertie and Bass Islands Formations (Upper Silurian)

STRATIGRAPHY: Bertie Formation found in southern Niagara Peninsula; Bass Islands Formation, the Michigan Basin equivalent of the Bertie Formation, does not significantly outcrop in Ontario but is present in the subsurface in southwestern Ontario; Bertie Formation represented by Oatka, Falkirk, Scajaquanda, Williamsville and Akron members. COMPOSITION: medium- to massive-bedded, micro-crystalline, brown dolostone with shaly partings. THICKNESS: 14 to 49 m. USES: quarried for crushed stone on the Niagara Peninsula at Fort Erie, Cayuga, Hagersville and Dunnville; shaly intervals are unsuitable for use as high-specification aggregate because of low freeze-thaw durability; has also been extracted for lime. AGGREGATE SUITABILITY TESTING: PSV = 46-49, AAV = 8-11, $MgSO_4$ = 4-19, LA = 14-23, Absn = 0.8-2.8, BRD = 2.61-2.78, PN (Asphalt & Concrete) = 102-120.

Oriskany Formation (Lower Devonian)

STRATIGRAPHY: basal Devonian clastic unit, found in Niagara Peninsula. COMPOSITION: thick- to massive-bedded, coarse-grained, grey-yellow sandstone. THICKNESS: 0 to 5 m. USES: has been quarried for silica sand, building stone and armour stone; may be acceptable for use as rip rap and well cemented varieties may be acceptable for some asphaltic products. AGGREGATE SUITABILITY TESTING: (of a well cemented variety of the formation) PSV = 64, AAV = 6, $MgSO_4$ = 2, LA = 29, Absn = 1.2-1.3, BRD = 2.55, PN (Asphalt & Concrete) = 107.

Bois Blanc Formation (Lower Devonian)

STRATIGRAPHY: Springvale Sandstone Member forms the lower portion of formation. COMPOSITION: a cherty limestone with shale partings and minor interbedded dolostones; Springvale Sandstone Member is a medium- to coarse-grained, green glauconitic sandstone with interbeds of limestone, dolostone and brown chert. THICKNESS: 3 to 40 m.

USES: quarried at Hagersville, Cayuga and Port Colborne for crushed stone; material generally unsuitable for concrete aggregate because of high chert content. AGGREGATE SUITABILITY TESTING: PSV = 48-53, AAV = 3-7, $MgSO_4$ = 3-18, LA = 15-22, Absn = 1.3-2.8, BRD = 2.50-2.70, PN (Asphalt & Concrete) = 102-290.

Onondaga Formation (Middle Devonian)

STRATIGRAPHY: correlated to part of the Detroit River Group; occurs on the Niagara Peninsula from Simcoe to Niagara Falls; contains the Edgecliff, Clarence and Moorehouse members. COMPOSITION: medium-bedded, fine- to coarse-grained, dark grey-brown or purplish brown, variably cherty limestone. THICKNESS: 18 to 25 m USES: quarried for crushed stone on the Niagara Peninsula at Welland and Port Colborne; high chert content makes much of the material unsuitable for use as concrete aggregate and asphaltic concrete; has been used as a raw material in cement manufacture. AGGREGATE SUITABILITY TESTING: (Clarence and Edgecliff members) $MgSO_4$ = 1-6, LA = 16.8-22.4, Absn = 0.5-1.1, PN (Asphalt & Concrete) = 190-276.

Amherstburg Formation (Middle Devonian)

STRATIGRAPHY: part of Detroit River Group; correlated to Onondaga Formation in Niagara Peninsula; contains Sylvania Sandstone Member and Formosa Reef Limestone. COMPOSITION: bituminous, bioclastic, stromatoporoid-rich limestone and dolostone with grey chert nodules; Formosa Reef Limestone is high purity (calcium-rich) limestone; Sylvania Sandstone Member is quartz sandstone. THICKNESS: 0 to 50 m; Formosa Reef Limestone up to 26 m. USES: cement manufacture, agricultural lime, aggregate. AGGREGATE SUITABILITY TESTING: PSV = 57, AAV = 19, $MgSO_4$ = 9-35, LA = 26-52, Absn = 1.1-6.4, BRD = 2.35-2.62, PN (Asphalt & Concrete) = 105-300.

Lucas Formation (Middle Devonian)

STRATIGRAPHY: part of the Detroit River Group in southwestern Ontario; includes the Anderdon Member which, in the Woodstock Beachville area, may constitute the bulk of the formation. COMPOSITION: light brown or grey-brown dolostone with bituminous laminations and minor chert; Anderdon Member consists of very high purity (calcium-rich) limestone. THICKNESS: 40 to 75 m. USES: most important source of high-purity limestone in Ontario; used as calcium lime for metallurgical flux and for the manufacture of chemicals; rock of lower purity is used for cement manufacture, agricultural lime and aggregate; Anderdon Member is quarried at Amherstburg for crushed stone. AGGREGATE SUITABILITY TESTING: PSV = 46-47, AAV = 15-16, $MgSO_4$ = 2-60, LA = 22-47, Absn = 1.1-6.5, BRD = 2.35-2.40, PN (Asphalt & Concrete) = 110-160.

Dundee Formation (Middle Devonian)

STRATIGRAPHY: few natural outcrops, largely in the subsurface of southwestern Ontario. COMPOSITION: fine- to medium-crystalline, brownish grey, medium- to thick-bedded, dolomitic limestone with shaly partings, sandy layers and chert in some areas. THICKNESS: 15 to 30 m. USES: quarried near Port Dover and on Pelee Island for crushed stone; used at St. Marys as a raw material for Portland cement. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-28, LA = 22-46, Absn = 0.6-6.8, PN (Asphalt & Concrete) = 125-320.

Marcellus Formation (Middle Devonian)

STRATIGRAPHY: subsurface unit, mostly found below Lake Erie and extending into the eastern U.S.A., pinches out in the Port Stanley area. COMPOSITION: black, bituminous shales. THICKNESS: 0 to 5 m. USES: no present uses.

Bell Formation (Middle Devonian)

STRATIGRAPHY: lowest formation of the Hamilton Group, no outcrop in Ontario. COMPOSITION: soft blue and grey calcareous shale. THICKNESS: 0 to 9 m. USES: no present uses.

Rockport Quarry Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group; no outcrop in Ontario. COMPOSITION: grey-brown, very fine-grained limestone with occasional shale layers. THICKNESS: 0 to 6 m. USES: no present uses.

Arkona Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: blue-grey, plastic, clay shale with occasional thin and laterally discontinuous limestone lenses. THICKNESS: 5 to 37 m. USES: has been extracted at Thedford and near Arkona for the production of drainage tile.

Hungry Hollow Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: grey crinoidal limestone and soft, fossiliferous calcareous shale. THICKNESS: 0 to 2 m. USES: suitable for some crushed stone and fill with selective quarrying. AGGREGATE SUITABILITY TESTING: No data.

Widder Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: mainly soft, grey, fossiliferous cal-

careous shale interbedded with blue-grey, fine-grained fossiliferous limestone. THICKNESS: 0 to 14 m. USES: no present uses.

Ipperwash Formation (Middle Devonian)

STRATIGRAPHY: upper formation of the Hamilton Group; very limited distribution. COMPOSITION: medium- to coarse-grained, grey-brown, bioclastic limestone. THICKNESS: 2 to 14 m. USES: no present uses.

Kettle Point Formation (Upper Devonian)

STRATIGRAPHY: occurs in a band between Sarnia and Erieau; small part overlain by Port Lambton Group rocks in extreme northwest. COMPOSITION: black, highly fissile, organic-rich shale with minor interbeds of grey-green silty shale. THICKNESS: 0 to 61 m. USES: possible source of fill; possible source of material for use as sintered lightweight aggregate.

Bedford Formation (Upper Devonian)

STRATIGRAPHY: lower formation of the Port Lambton Group. COMPOSITION: soft, grey shale. THICKNESS: 0 to 33 m. USES: no present uses.

Berea Formation (Upper Devonian)

STRATIGRAPHY: middle formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: grey, fine- to medium-grained sandstone, often dolomitic and interbedded with grey shale and siltstone. THICKNESS: 0 to 60 m. USES: no present uses.

Sunbury Formation (Upper Devonian)

STRATIGRAPHY: upper formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: black shale. THICKNESS: 0 to 20 m. USES: no present uses.

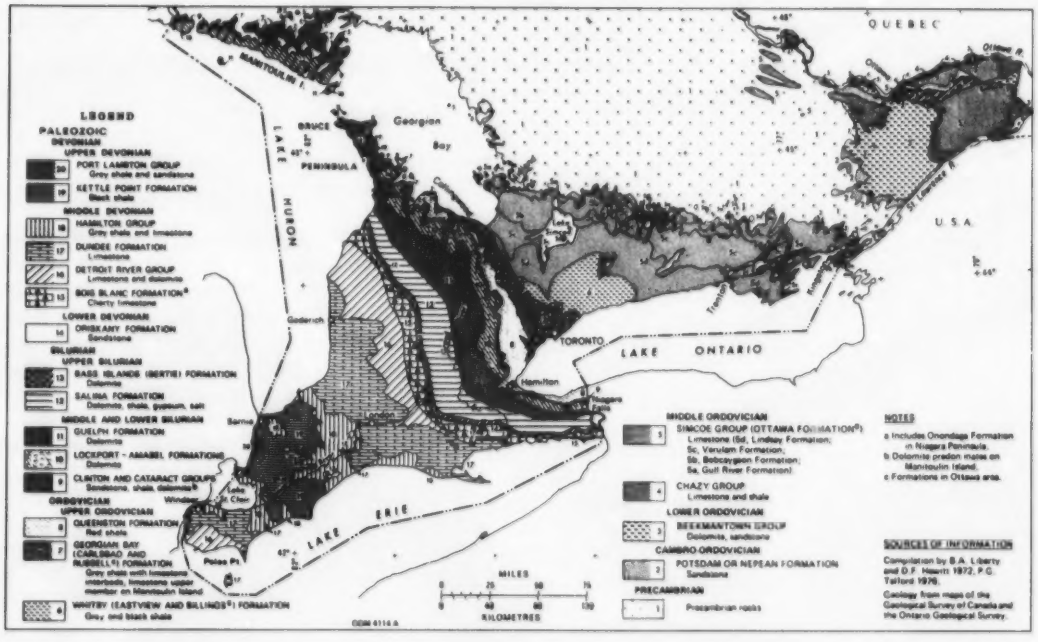

Figure D1. Bedrock geology of southern Ontario.

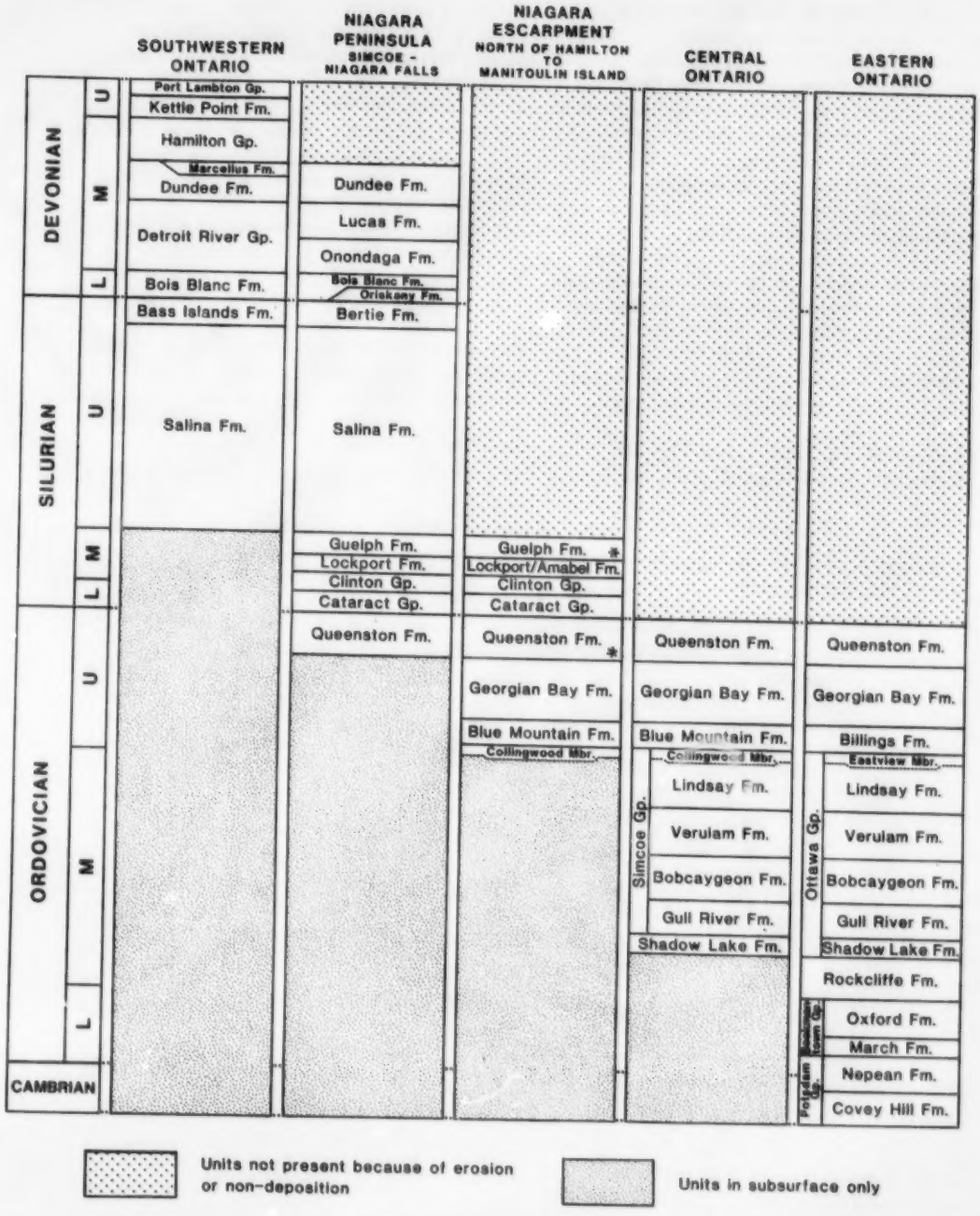

Figure D2. Exposed Paleozoic stratigraphic sequences in southern Ontario
(adapted from: Bezys, R. K. and Johnson, M.D. 1988. The geology of the Paleozoic formations utilized by the limestone industry of Ontario; The Canadian Mining and Metallurgical Bulletin, v.81, no.912, p.49–58).

Appendix E — Aggregate Quality Testing

Four types of aggregate quality tests have been performed on selected samples from the project area. A description and the specification limits for each test are included in this appendix. Although a specific sample meets or does not meet the specification limits for a certain product, it may or may not be acceptable for that use based on field performance. Additional quality tests other than the four major tests listed in this appendix can be used to determine the suitability of an aggregate. The above four types of tests were performed by the Ontario Ministry of Transportation.

Absorption Capacity Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate. This test is conducted in conjunction with the determination of the sample's relative density.

Los Angeles Abrasion and Impact Test This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium Sulphate Soundness Test This test is designed to simulate the action of freezing and thawing on aggregate. Those aggregates which are susceptible will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Petrographic Examination Individual aggregate particles in a sample are divided into categories good, fair, poor and deleterious, based on their rock type (petrography) and knowledge of past field performance. A petrographic number (PN) is calculated. The higher the PN, the lower the quality of the aggregate.

TABLE E1. SELECTED QUALITY REQUIREMENTS FOR MAJOR AGGREGATE PRODUCTS.

	TYPE OF TEST				
	COARSE AGGREGATE				FINE AGGREGATE
TYPE OF MATERIAL	Petrographic Number Maximum	Magnesium Sulphate Soundness Maximum % Loss	Absorption Maximum %	Los Angeles Abrasion Maximum % Loss	Magnesium Sulphate Soundness Maximum % Loss
Granular A	200	–	–	60	–
Granular B Type I	250*	–	–	–	–
Granular M	200	–	–	60	–
Select Subgrade Material	250	–	–	–	–
Surface Treatment Class 1	135	12	1.75	35	–
Surface Treatment Class 2	160	15	–	35	–
Surface Treatment Class 3	160	12	2.0	35	–
Surface Treatment Class 4	–	–	–	–	20
Surface Treatment Class 5	135	12	1.75	35	–
Hot Mix – HL 1	100	5	1.0	15	16
Hot Mix – HL 2	–	–	–	–	20
Hot Mix – HL 3	135	12	1.75	35	16
Hot Mix – HL 4	160	12	2.0	35	20
Hot Mix – HL 8	160	15	2.0	35	20
Structural Concrete, Sidewalk, Curb, Gutter and Base	140	12	2.0	50	16
Pavement Concrete	125	12	2.0	35	16

* requirement waived if the material has more than 80% passing the 4.75 mm sieve.

(Ontario Provincial Standard Specifications OPSS 304, OPSS 1002, OPSS 1003 and OPSS 1010)

CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

MAPS
NOT
FILMED

CARTES
OMISES